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MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. CXII.

EDITED BY

JAMES FORREST, ASSOC. INST. C.E., SECRETARY.

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CORRIGENDUM.

Vol. ci. p. 277, column 4 of Table, line 5, the expression should read—

$$\frac{14{\cdot}18\ n\ \pi\ \mathrm{WR}^3}{\mathrm{G}\ s^4}.$$

THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1892-93.—PART II.

SECT. I.—MINUTES OF PROCEEDINGS.

10 January, 1893.

HARRISON HAYTER, President.
in the Chair.

It was announced that the several Associate Members hereunder mentioned had been transferred to the class of

Members.

MAURICE DEACON.
JOHN WILLIAM HERRING.
WALTER MERIVALE.
THE HON. CHARLES ALGERNON PARSONS, B.A.

Also that the following Candidates had been admitted as

Students.

CHARLES STEUART BETTON.
PERCY RHODES COBB.
FREDERICK CHARLES DASHPER.
JOSEPH MERRICKS GAVIN.
CHARLES HENRY GODFREY.
JOHN FREDERIC CHARLES KIMBER.
JOHN WILLIAM KITCHIN.
CYRIL D'ARCY LEAVER.
ANDREW GRIEVE MACKINLAY.
ALBERT WATERLOW MAKOVSKI.
GEORGE NELSON.
HORACE FARR SIMPSON.
WILLIAM SIDNEY SMITH.

The Candidates balloted for and duly elected were: as

Members.

JOHN BENTON, F.C.H.
JOHN COOM.

Associate Members.

PIERCIE SEVERN ANDERSON, Stud. Inst. C.E.
CYRIL FRANCIS BENGOUGH.
FREDERICK WILLIAM BOWDEN.
FRANK CLAYTON, F.C.H., Stud. Inst. C.E.
HUGH MORTIMER HERBERT COLLIER.
JOHN COOK.
SAMUEL EDWARD COOPER, Stud. Inst. C.E.
FRANCIS EDWARD DIXON.
KINSLEY DRYDEN DOYLE, B.E.
THOMAS DUXBURY.
EDGAR HUNTER FAIRGRIEVE, B.Sc., Stud. Inst. C.E.
HENRY FIDLER.
JOHN RICHARD STRATFORD FOX, Stud. Inst. C.E.
GEORGE LAMBERT GIBSON, Stud. Inst. C.E.
THOMAS BENJAMIN GRIERSON.
JOHN GWYNN GWYNNETH.

Associate Members—continued.

JOHN HARTLEY.
SYDNEY THOMAS EDWARD HEATON-ELLIS, Stud. Inst. C.E.
JOHN LLEWELLYN JEKEN.
HARRY KELLETT.
HARRY BIRCH KILLON.
WILLIAM THOMAS LEWIS.
WILLIAM LUNN.
WALTER MARKBY, Stud. Inst. C.E.
GEORGE SOMERS MATHEWS.
ARTHUR ERNEST MAYES.
MICHAEL CHARLES MEABY.
ERNEST HERBERT MITCHELL.
ARTHUR HENRY MOUNTAIN.
MATTHEW PATERSON.
STANLEY ARTHUR ROYLE, Stud. Inst. C.E.
JOHN ROXBURGH SHARMAN, Stud. Inst. C.E.
WILLIS WIGG.
ERNEST ARTHUR BORAMAN WOODWARD, Stud. Inst. C.E.

Associate.

FREDERIC JULIUS MACAULAY.

(*Paper No. 2662.*)

"Gas-Power for Electric Lighting."

By JOSEPH EMERSON DOWSON, M. Inst. C.E.

IN this country gas-engines developing in the aggregate more than 7,000 HP. have been sold for electric lighting, and the makers of the Otto engine in Germany state that 934 of their engines, capable of giving over 11,000 HP., are now used for about 1,100 arc-lamps and about 90,000 glow-lamps. It is, however, only within the last few years that gas-engines of large size have been before the world in a practical form; and it is not surprising that, as yet, electricians have not used them extensively in central-stations. Moreover, other subjects, such as the use of high- or low-tension currents, the adoption of storage-batteries, transformers, &c., have until lately occupied more attention than that of the excessive cost of fuel and wages. In April 1891, the question of load-factor was discussed fully by Mr. R. E. B. Crompton,[1] who stated that, in 1890, at Kensington, the load-factor was only 2·5 in August, and 21·6 in December, whilst the fuel-consumption was 12·8 lbs. and 7·9 lbs. respectively per kilowatt; at St. James' and Pall Mall the load-factor was 6·8 in August and 39·5 in December, whilst the fuel-consumption was 9·2 lbs. and 7·5 lbs. respectively per kilowatt. He further expressed a belief that, at that time, those stations contained the most economical type of generating-apparatus.

[1] *Vide* "The Cost of the Generation and Distribution of Electrical Energy," Minutes of Proceedings Inst. C.E., vol. cvi.

Since then, although improvements have been made in several stations, the load-factor continues to perplex the electrician; and it is especially with reference to this question that the Author has brought forward this Paper. He hopes to be able to show that much of the present loss due to fuel, water and wages, can be avoided if gas-power is used instead of steam-power. To effect this, he advocates the use of engines driven with generator-gas; but he also notices the advantages of working engines, in certain cases, with ordinary town-gas.

Dessau.—The first important central-station worked by gas-power, was opened at Dessau, in the Duchy of Anhalt, in September, 1886. A noteworthy feature in connection with this installation is that it was established by the German Continental Gas Co., in the belief that it would not only promote the use of their gas during the day-time, but cheapen the production of light. It was an enterprising experiment on a fairly large scale, which has been so far successful that it has been greatly extended; and the Company is about to establish electric-lighting stations in other towns where it has gas-works. The greatest difficulty is that, in a quiet provincial town such as this, the number of hours during which the lamps are used is small. An account of the works was given by Mr. W. von Oechelhäuser, and appeared as a translation in the *Journal of Gas-Lighting* of the 5th and 12th January, 1892. The following particulars are derived partly from this Paper, and partly from data given to the Author at Dessau in October last.

When the station was opened in 1886, the largest gas-engine made gave only 60 IHP. (effective) with two cylinders. They then had two 60-IHP., one 30-IHP., and one 8-IHP. (effective) engines, and all the dynamos were driven by belting and counter-shafts. In 1891, a considerable change was made, as the result of five years' experience, and as larger gas-engines were then constructed. They retained one engine of 60 IHP. (effective), with its belting and counter-shaft, and substituted for the other engines one of 120 IHP. (effective), coupled direct to its dynamo. There are now 62 arc-lamps, and glow-lamps equal to 4,000 of 16 candle-power each. In future, it is intended to have all dynamos coupled direct to the engines, in order to avoid loss in friction and slip of the belting, and to make the station as compact as possible. The last point is considered of great importance, as the engines and dynamos can then be placed in a confined space in the centre of the district to be lighted, the gas being produced where the ground is less costly, and conveyed in a pipe to the engines. With steam-power, it is

often difficult and expensive to place the station in a busy centre; and, if the station is far from its work, the cables are costly, and there is a great loss of current. The speed of the engine and coupled dynamo is 150 to 160 revolutions per minute, and the output is 70 to 80 kilowatts per hour, the consumption of town-gas being at the rate of 39 cubic feet per kilowatt per hour at the terminals of the dynamo. The dynamo is of Fritsche and Pischon's Radanker type, and, following the custom now prevailing to some extent in Germany, is specially designed for a low speed. It may be added that Messrs. Körting, of Hanover, have also recognised the importance of coupling the engine and dynamo, and make what they call a "gas-dynamo" to work with their gas-engine. They state that, with this combination, one glow-lamp of 16 candle-power can be obtained with $2\frac{1}{8}$ cubic feet of gas per hour; and this result is similar to that obtained at Dessau. At the latter place, the 60-HP. (effective) Otto engine, with counter-shaft and two belts, requires gas at the rate of $2\frac{1}{3}$ cubic feet per 55 watts per hour, and the loss between the engine and terminals of the dynamo is about 20 per cent.; whereas, with the dynamo coupled direct, the loss is about 10 per cent. The makers of the Otto-engines in Germany now guarantee that their new 120-HP. (effective) engine requires only 22 cubic feet of gas per brake HP. per hour; and Mr. von Oechelhäuser states that with another engine he is hopeful of getting the consumption down to 17·6 cubic feet of gas per brake HP., when one kilowatt can be produced with a consumption of about 30 cubic feet of ordinary town-gas.

The following is a quotation from Mr. von Oechelhäuser's Paper: "Formerly, without accumulators, it was thought necessary to adjust the size of the engine to the supply—small engines for a small supply, large ones for a large supply—so that they should always be worked to their full extent. But the need for small and medium-sized engines has disappeared, inasmuch as a limited supply can more advantageously be furnished entirely by accumulators without any engine, and as the lack of load required to work the engines fully is compensated for by charging accumulators. For, in spite of the loss of about 21 per cent. in the accumulators, large engines act more beneficially when working in parallel than smaller ones serving the distributing-mains direct without accumulators. In the first place, large engines require 25 to 30 per cent. less gas per effective HP. than small ones, and, in the second place, they always run with a full load when worked in parallel with accumulators; while smaller

engines, notwithstanding their adaptability in size, are seldom worked fully when serving direct. Therefore the large motors and their full load not only compensate for the loss in the accumulators, but lead even to increased economy in various directions, and afford many other advantages."

This confirms what Mr. Crompton stated in 1891, to the effect that "the mere addition of accumulators to meet 10 per cent. only of the output of the twenty-four hours, is sufficient to reduce the cost of the material used by 30 per cent., and that of the labour by 33 per cent.; whereas the increase of cost due to the maintenance of accumulators is small, so that the result is to reduce the total cost of production by 28 per cent."

Schwabing.—Since February, 1889, the Municipality of Schwabing, a suburb of Munich, has used an Otto engine worked with Dowson gas for 10 arc- and about 300 glow-lamps for lighting the streets; and one year after it was started, the Burgomaster, upon the report of Mr. Uppenborn,[1] Appendix G, certified that all was satisfactory. Among other interesting facts, he states that the variation in speed of the dynamo was only 1 per cent.; and brake-trials made with the engine show that the fuel-consumption was 1·54 lb. per brake HP. per hour—1·32 lb. of anthracite and 0·22 lb. of coke. Recently, Messrs. Schur & Company, who supplied the plant, informed the Author that, in a trial lasting 8¼ hours, with an average output of 22·5 kilowatts per hour, the fuel-consumption was 3·3 lbs. per kilowatt per hour. It is added that "the cost of repairs since starting has been practically nothing, and no interruption in the electric lighting has occurred."

Morecambe.—This town is now lighted by 9 arc-lamps, and glow-lamps equivalent to 1,600 of 8 candle-power each; the results of trials made by the engineers are given in Appendix H. At first, the engines were driven with town-gas at 3*s.* 3*d.* per 1,000 cubic feet, and with an output of 1,600 to 1,800 kilowatts per week: the cost of gas per kilowatt delivered was about 1½*d.* When the engines were afterwards worked with Dowson gas, the busy season was over, and the output was at the rate of only 1,155 kilowatts per week. The engines were running with a light and variable load, the consumption of fuel was 2·58 lbs., and the cost of the gas, including wages and fuel, was ½*d.* per kilowatt generated.

Longpont.—At Mr. Say's chateau there are 650 glow-lamps and one arc-lamp, and the results of a trial made in September last

[1] The full text of his Report was published in the "Centralblatt für Elektrotechnik," vol. xii. 1889.

(Appendix I) show that the total consumption of fuel with a Crossley engine working with Dowson gas was 1·2 lb. per I.HP. per hour, and 2·7 lbs. per kilowatt per hour. An indicator diagram is given in Fig. 20.

The Author believes that the late Sir William Siemens first drew attention to the fact that when illuminating-gas is burnt in a gas-engine to drive a dynamo, much more light is produced electrically than can be produced by burning the same quantity of gas in burners in the usual way. At all events, so long ago as 1879, he stated, in evidence before a Select Committee of the House of Commons, that with a dynamo driven by a gas-engine, 19·5 cubic feet of 18 candle-power gas produced an arc-light equal to 1,000 standard candles, whereas 312·5 cubic feet of gas would be required to give the same light in Argand burners. Since that time, the consumption of gas per HP. in engines of larger size has been considerably reduced; and it is not too much to say that now the ratio is 20 to 1 in favour of converting the gas into an arc-light by means of a gas-engine. At the period referred to, the glow-lamp was not in use, and the Author has collected data from various sources, as to the consumption of ordinary town-gas by engines serving glow-lamps, with and without accumulators. The returns sent him are given in Appendixes J and K, and he acknowledges his indebtedness to those who have assisted him in compiling these returns. As Sir David Salomons has pointed out (Appendix L), much depends on whether a counter-shaft is used, on the size of the engine, on the construction of the dynamo, and on the quality of the gas. In his case, with a 14-HP. (nominal) Crossley engine, and with a friction load of 7 HP., the consumption of gas is about 39 cubic feet per kilowatt at the terminals of the dynamo. The average of all the returns given in Appendix K, with engines under varying loads and without accumulators, is about 47 cubic feet per kilowatt-hour: when accumulators are used, the consumption of gas is less. If, however, 47 cubic feet of gas are allowed to produce 1 kilowatt, and if 55 watts give a light of 16 candle-power, one of these lights will require only 2·6 cubic feet per hour; whereas, a standard Argand burner requires 5 cubic feet per hour. This shows a saving of about 50 per cent. in favour of burning the gas in the engine and in producing the light electrically, and such a saving deserves careful consideration.

In the comparison just made it is assumed that the glow-lamps and gas-burners are in good order; but it must not be inferred that under ordinary working conditions they maintain so

high a duty. In an Address given last year by Mr. W. H. Preece to the Members of the Incorporated Association of Municipal and County Engineers, special attention was drawn to this point. He and Mr. Vernon Harcourt had made careful experiments at the General Post Office, to determine the average illumination from the gas-burners in use, and they found that the ordinary burner, supposed to be giving a light of approximately 16 candle-power, with a consumption of 5 cubic feet of gas per hour, really gave only 10 candle-power. This great falling off in light was believed to be due partly to dirt in the burner, but chiefly to the flickering of the flame caused by draughts in the rooms. As regards glow-lamps, it is well known that their light is affected by volatilized carbon and dust deposited on the bulbs.

The question of load-factor is doubtless a serious one with any type of engine; but with gas-engines, the loss is much less than with steam-engines. When a gas-engine is stopped, its consumption of fuel stops also, and there is no furnace to maintain; nor is there any water to boil at starting. At the same time, it is desirable that the gas-engine should be worked as much as possible under a full load; and in this respect the experience at Dessau is generally confirmed. A central-station is certainly worked under very trying conditions, and, in the London district, there is only a full out-put of current during 3 to 5 hours in every 24; moreover, about 60 per cent. of the total out-put is required during that short period. In practice, this means that in a station where the current is supplied direct, without accumulators, the engines are run at a reduced speed during a portion of the time, and at other times some of them are stopped altogether; but all must be ready to work in the evening, and occasionally in the daytime when there is fog. The consumption of fuel in a furnace cannot, however, be closely adjusted to a varying demand for steam; and a boiler delivering half its maximum production will certainly require more than half the allowance of coal necessary for the maximum. Mr. Crompton recently informed the Author that, in consequence of certain improvements at the Knightsbridge Central-Station, where there are accumulators, the engines there now work under nearly full load, and that the average fuel-consumption is as low as 6·2 lbs. of coal per kilowatt delivered. At Chelsea, the consumption is reported to be only 5·8 lbs. per kilowatt-hour, and, speaking generally, it may be assumed that, at the present time, the average consumption is over 6 lbs. per kilowatt where accumulators are used, and from 9 to 12 lbs. where they are not used. In any case,

with the best possible arrangement of steam-power, there must be a large amount of fuel consumed which does no useful work; for even if some of the fires are drawn, they have to be re-lighted, and the large quantity of water which has cooled during the time of standing must be re-heated. The question has greatly exercised the minds of engineers, and, in an article advocating the use of gas-engines, Mr. J. Swinburne pointed out in *Industries* of the 17th July, 1891, "it does not much matter whether a dynamo gives 95 per cent. or 96 per cent. efficiency, if there is a consumption of 20 lbs. of coal per electrical HP. delivered per hour. The labour spent in securing the odd 1 per cent. in the dynamo would be infinitely more profitably applied to studying the behaviour of various engines and boilers under the very abnormal conditions that obtain in central stations."

The Author believes that the solution of the difficulty is to be found in the use of gas-plant instead of steam-plant. In the first place, it is beyond doubt that, with a large engine, one brake HP. per hour can be obtained with a consumption of about 1 lb. of anthracite or $1\frac{1}{8}$ lb. of coke; whereas the consumption of coal, with the steam-engines now used for central-stations, must be taken at about $2\frac{1}{2}$ lbs. per brake HP., when working under a full load. A saving of not less than 50 per cent. can therefore be made in stations where the engines are fully loaded; and where there are great fluctuations in the output, the loss of fuel with boilers not used, or only partly used, can be almost entirely avoided. For a maximum of 400 kilowatts, there would be three gas-generators, Fig. 2, Plate 1, each capable of making one-third of the maximum quantity of gas required. The production of gas can be raised or lowered to a considerable extent by varying the pressure of the steam in the boiler, and the supply of steam to the injector can also be governed automatically by the rise and fall of the gas-holder. Moreover, the working of each generator can be stopped immediately by shutting off its steam-supply. Supposing, therefore, that all three generators are working at their maximum rate when a gradual reduction is required, this is effected automatically in the last-mentioned simple way; or, if preferred, the boiler-pressure can be reduced. When the production of one or two generators can be dispensed with, their working is at once stopped by shutting off steam. The third generator can then be kept at work, and its production adjusted to suit the minimum consumption required. A gas-generator has a small grate-area compared with that of a boiler, and much less cooling surface; it contains no water, and requires no chimney-draught. Actually, a generator of the size

referred to loses only 6 or 8 lbs. per hour whilst standing. If, therefore, an average of only 40 per cent. of the maximum power is required during 21 hours, it is equivalent to letting two of the generators stand for that period; and, at 8 lbs. each per hour, this means a total loss of only 3 cwts., compared with the much greater waste when steam-power is used. It has been seen that, in certain cases, ordinary town-gas may be used with advantage for electric-stations, and, in his Cantor Lectures at the Society of Arts in February last, Professor George Forbes urged its adoption for "sub-stations." But for large powers, by far the cheapest way is to work the engine with generator-gas made from anthracite or common gas-coke; and, as this system applied to large powers is of recent date, the Author thinks that a brief survey of what has been accomplished may be desirable.

Without entering into the historical question as to who may have been the first inventor of fuel in the gaseous form, it may be said, without fear of contradiction, that its introduction in a practical way was certainly due to the skill and enterprise of the late Sir William Siemens. In ordinary producer-gas, however, as made in the Siemens and other producers, there is seldom more than 8 to 10 per cent. of hydrogen; therefore, to develop high temperatures in furnaces with gas of low calorific power, Sir William Siemens adopted the well-known regenerative system. He even went so far as to design a gas-engine with a regenerator, but it was not perfected. The idea was a tempting one, as the loss of heat through the walls of the cylinder, and in the exhaust, is very serious; but there are many practical difficulties to be overcome, such for instance as the expansion and pre-ignition of the explosive mixture. It is well known that the efficiency of a gas-engine, considered as a machine for converting the heat energy of the fuel into work, depends chiefly on the difference between the initial and the final pressures developed in the cylinder. In other words, the mixture of gas and air in the cylinder must be strong enough to light promptly, and to develop a high temperature at the beginning of the stroke; also the engine must be constructed so as to convert as much as possible of the heat into work during the stroke. With ordinary producer-gas this is impossible, as it lights slowly and develops too little heat. An obvious way of meeting the difficulty, is to replace some of the nitrogen in producer-gas by an equal volume of hydrogen. This the Author has succeeded in doing, by forcing superheated steam through the generator-fire, and by always having a depth of compact red-hot fuel sufficient to ensure the decomposition of as

much steam as possible, without the accompaniment of a large excess of carbonic acid. The result is that gas made in this way contains about 25 per cent. of carbonic oxide and 19 per cent. of hydrogen, according to Dr. William Foster,[1] or 22·5 per cent. of carbonic oxide and 26 per cent. of hydrogen, according to tests made by Dr. Langer for Mr. Ludwig Mond. Such a gas as this can be lighted promptly in the cylinder of an engine, and its calorific power is sufficient to develop the high initial pressure required.

For powers up to about 80 HP. (effective) the type of gas-apparatus shown in Fig. 1, Plate 1, is the one usually adopted. It consists of a small steam-boiler with superheating-tubes, a gas-generator, a gas-cooler, a hydraulic box, a sawdust scrubber, and a gas-holder and tank, the latter of which contains an inner tank filled with coke. In this way, before the gas reaches the gas-holder, it passes through cooling-pipes, then through water twice, and finally through coke and sawdust. The rise and fall of the gas-holder is made to regulate the supply of steam to the injector, so that, to a certain extent, the production of gas can be regulated automatically to suit a varying rate of consumption. The gas-holder is not usually of large size, as the generator makes gas as quickly as it is consumed, and there is no more need of a large reserve of gas for a gas-engine than there is of a large reserve of steam for a steam-engine. The cost of a plant of this type for 80 HP. (effective), including erection, foundations, and ash-pit for generators, is about £325. When large powers are required, the gas-plant is differently arranged, and Fig. 2, Plate 1, shows the plan recommended for a central-station requiring a maximum of about 400 kilowatts, or about 530 HP. (effective). In this there are three generators, each capable of supplying about one-third the maximum power, and each generator has its cooler, hydraulic box, and scrubbers, so that they can be worked together or singly. The cost of this plant, including erection, foundations, and ash-pit for generators, is about £1,100. If the gas-plant is all on one level, as shown in Fig. 2, it occupies a ground-space of about 27 feet by 54 feet; but, if necessary, all except the gas-holder can be placed under or over the engine-room; or the gas-holder can be at some distance from the rest of the plant. The engines are shown with two cylinders, end to end, as suggested by Messrs. Crossley; and, as they can be run at a speed of 250 revolutions per minute, the dynamos are shown coupled to the crank-shafts, as at Dessau and elsewhere. The cost

[1] See "Cheap Gas for Motive Power." Minutes of Proceedings Inst. C.E., vol. lxxiii., p. 320, Table I.

of the four engines fixed complete, including foundations, is about £3,000. In the Author's Paper on "Gas-Power compared with Steam-Power,"[1] he gave numerous examples of the cost of working gas-engines; but at that time (1887) the largest engine with twin cylinders indicated only about 80 IHP. At the present time, there are several single-cylinder engines indicating 85 to 100 IHP., and twin-cylinder engines indicating over 170 IHP.; and there will shortly be one indicating about 375 IHP. In the present Paper it is proposed to deal more particularly with the larger powers, and, as the practical worth of an engine depends so much on its working-cost, the Author has done his best to obtain the actual results of engines working regularly with Dowson gas, under the usual conditions obtaining in factories. These results are here stated briefly, and further particulars will be found in the Appendixes.

1. *Chelsea.*—Messrs. Mead and Son have a 60-IHP. (nominal) Crossley engine with twin cylinders, which has worked regularly at their flour-mill for about a year. After the engine had worked about three months, a trial lasting 8 hours was made by the Author, while the work of the mill was going on. It was confirmed by a second day's run, and gave these results:

—	Left Cyl.	Right Cyl.	Both Cyls.
Mean pressures of indicator diagrams in lbs. per square inch. (See Figs. 3 and 4, Plate 2.)	79·9	77·9	78·9
Average I.HP. during trial, with speed of about 156 revs.	59·3	59·4	118·7
Maximum I.HP. with full speed of 160 revs.	..	..	173·6

Anthracite consumed in the generator during trial	0·615 lb.	per I.HP.	per hour.
Coke consumed in the boiler during trial	0·147	,,	,,
Total during trial	0·762	,,	,,
Anthracite put in the generator on the morning after trial, to make up for loss during nine night hours, 56 lbs.	0·058	,,	,,
Ditto to make up for loss when raking out clinkers, etc., 50 lbs.	0·053	,,	,,
Total loss during the night, and after clinkering on the following morning, 106 lbs.	0·111	,,	,,
Water for cooling the engine	5 gallons	,,	,,
,, boiler of gas-plant	½ pint	,,	,,
,, washing, gas, etc.	1 ,,	,,	,,

[1] Minutes of Proceedings Inst. C.E., vol. lxxxix. p. 320.

The mill was formerly worked by a compound beam-engine, made by Messrs. S. Horn and Co., and a smaller engine, by Messrs. Wentworth and Co. The beam-engine was only ten years old, and both were in good order. A report on a trial of this engine is given in Appendix B, and indicator diagrams are shown in Figs. 3 and 4, Plate 2. Messrs. Mead and Son state that, with steam-engines, they formerly consumed 4 tons of best Welsh coal in 24 hours, and that, to do the same work with gas-power, they consumed only 30 cwt. of anthracite, at the same price per ton as steam-coal, the saving being no less than 62 per cent. They consider the governing of gas-engines better than that of steam-engines. The cost of wages and lubrication is about the same as for steam.

2. *Newtown.*—The Severn Tweed Company have three large Crossley engines and one small one, which are capable of indicating an aggregate of about 280 HP. They made two independent trials, each lasting 6 working days (56 hours), one trial being with anthracite in the generator, and the other with ordinary gas-coke. The first trial gave a total consumption (including slack for steam boiler) of 1·23 lb., at a cost of 0·13*d.* per brake HP. per hour. The second trial showed a total consumption of 1·73 lb., at a cost of 0·135*d.* per brake HP. per hour. In this mill there are eighteen spinning-mules and other machines, which require a constant speed; and it was feared by the owners of the mill that on this account the gas-engines might not be suitable, but these fears have proved groundless. Results of working and other particulars are given in Appendix C; Figs. 5, 6, and 7, Plate 2, show the indicator diagrams.

3. *Godalming.*—At the paper mills of Messrs. Spicer and Co. there are several Crossley engines; and from August to December 1891, the owners kept a strict account of all the fuel used, during which time the engines worked night and day (except Sundays). The work varied very little, the average power used was 210 I.HP., and the total fuel used in the gas-generators and boiler, including waste of all kinds, averaged 1 lb. per I.HP. per hour. It may be added that in 1888 Messrs. Spicer began with about 85 I.HP., that in 1889 they increased this to 240 I.HP., and that in February 1892 they put in an additional large engine, which has brought up the total to 410 I.HP. They have since decided to further increase their gas-power with a twin-engine, each cylinder of which is to give 150 brake HP.

4. *Openshaw.*—At Messrs. Crossley's works, about 300 I.HP. is derived from gas made from anthracite in a Dowson plant, and

they state that, during a trial lasting 35 weeks, their average consumption of anthracite was about 1 lb. per I.HP. per hour. In confirmation of this, they now guarantee that, under ordinary conditions of working, their large engines will not consume more than 1 lb. of anthracite, or 1¼ lb. of coke, converted into gas, per I.HP. per hour.

5. *Wandsworth.*—The Projectile Company have an engine similar to the one at Chelsea, also a single-cylinder engine of 30 HP. (nominal). They are often used night and day, and the manager states that they do their work well, and that the cost of fuel (anthracite for generator, and steam-coal for boiler), is about half what it was with steam-power for the same work. Indicator diagrams of these engines are given in Figs. 8 and 9, Plate 2.

6. *Halifax.*—Messrs. Carter and Co., of the Dunkirk Cloth Mills, have 4 Crossley engines, of a maximum aggregate of about 200 I.HP., used for fast looms, as well as a variety of other machines. The gas is entirely made from ordinary gas coke, and, after two years' experience, they state that their power varies from 160 I.HP. to 180 I.HP., and that the coke consumed averages about 1·4 lb. per I.HP. per hour, the engines being of comparatively small size. Fig. 10, Plate 2, shows an indicator diagram of one of these engines.

There are many other installations of importance, such as that of Messrs. Armstrong, Mitchell, and Co., of Elswick, who have a plant for 250 I.HP.; the Russian Government, too, have 90 I.HP. at Warsaw, and 65 I.HP. at Kowno, the power being used at both these places for grinding corn, and for working electric search-lights in the fortresses. In these cases, however, the Author does not know the fuel-consumption. He also regrets his inability to give the brake HP. of the engines above referred to, so as to determine the ratio of brake to indicated HP.; but such brake trials could not be made without considerable expense and great inconvenience to the owners of the engines. Unfortunately, in this country, it is still customary to sell engines by an arbitrary commercial nominal HP.; sometimes the indicated HP. is given also, but seldom the brake HP. On the Continent it is invariably the practice to give the brake HP., and not the indicated. In neither case, therefore, is the record complete, but in his Paper on "Gas-Power compared with Steam-Power,"[1] the Author gave several examples of engines tested for their brake and indicated horse-powers; and in the *Society of Arts Journal* of the 13th March, 1889,

[1] Minutes of Proceedings Inst. C.E., vol. lxxxix.

will be found Professor Kennedy's determinations, which are most valuable. Believing that enough information already exists as to the consumption of ordinary town-gas per brake HP., the Author has now collected some further information as to the fuel-consumption per brake HP., of engines working with Dowson gas.

1. *Rouen* (September, 1886).—Figs. 11 and 12, Plate 2, are indicator diagrams of a Delamare-Debouteville engine working with Dowson gas. When there were late ignitions, as in Fig. 11, the engine gave 25 brake HP.; but when the lighting-port was advanced so as to give earlier and more regular ignition, the brake-power of the engine fell off considerably. This effect is noteworthy, and is made a point of by the designers of the engine, who consider *sine quâ non* that the charge in the cylinder shall not be fired until the crank is well over the dead-point. They say that in this way they avoid waste of energy, and that there is less time allowed for the cooling of the gases by the walls of the cylinder immediately after the explosion. Although the Otto cycle is used, the consumption of gas per brake HP. is less than in an ordinary Otto engine, and this is supposed to be due to the above cause. The mechanical efficiency of this engine was 80 per cent. The fuel consumption was 0·92 lb. per indicated HP. and 1·15 lb. per brake HP. per hour. In September 1890, Professor Witz, of Lille, made a careful trial of a single-cylinder Delamare-Debouteville engine, which developed 75 brake HP. when working with Dowson gas. Full details are given in a report of the trial, which was published in *Engineering* of the 17th April, 1891. Two of the characteristic diagrams above referred to are given in Figs. 13 and 14. Many of the diagrams are still more irregular, and it was not easy to determine the mean pressures; but Professor Witz made the I.HP. 111·9, so that the loss in friction was more than 35 HP. The makers, Messrs. Powell, expected that the engine would give 100 brake-HP., and admitted that the shafting and gearing of the engine were too heavy for the actual power developed; the Author has since been informed that some modifications have been made which have raised the mechanical efficiency considerably. Notwithstanding this serious and unusual loss in friction, it is somewhat remarkable that the fuel consumption, in a 24 hours' continuous run, was only 1·34 lb. per brake HP. per hour. Of this, 1·13 lb. was anthracite consumed in the generator, and 0·21 lb. coke used in the boiler. If this engine had been as well designed as the 25-HP. engine above referred to, the fuel consumption would doubtless have been still lower.

2. *Deutz* (April, 1887).—Professor K. Tiechmann, of the Royal Technical High School, Stuttgart, and Mr. F. Böcking, the chief engineer of the Rhenish Society for Inspecting Steam-Boilers, made a trial of a twin-cylinder Otto engine, which developed an average of a little over 52 brake HP. In their report, Appendix D, they stated that it worked 310·7 brake HP. hours, and consumed 1·67 lb. per brake HP. per hour, of which 1·48 lb. was anthracite in the generator, and 0·19 lb. was coke in the boiler. Fig. 15 represents an indicator diagram taken during the trial.

3. *Nürnberg* (December, 1888).—Two brake trials of a 30-HP. (effective) Otto engine worked with Dowson gas, at the brewery of Baron von Tucher, were made by Mr. P. Beck, of Augsburg. In one trial the total fuel consumed was 1·97 lb., and in the other 1·94 lb. per brake HP. per hour. Further details are given in Appendix E.

4. *Canale* (January, 1890).—In consequence of a dispute which arose as to the performance of a 40-HP. (effective) Otto engine worked with Dowson gas, a committee of four experts was appointed by the High Court of Turin, and was assisted by Mr. Cesare Monaco, analytical chemist of the Royal Industrial Museum, to make a thorough investigation, and report. A translation of so much of the report as refers to the working of the engine and gas plant is given in Appendix F; and, briefly stated, the following were the results arrived at: Samples of the anthracite used in the generator, of the gas passed into the holder, and of the exhaust gases from the engine, were analysed. A brake trial of 8 hours showed that, while the engine developed 36·45 brake HP., the total fuel consumed was 1·9 lb. per brake HP. per hour. Of this 1·62 lb. was anthracite, and 0·28 lb. was coke. The analysis of the gas made in the generator showed the presence of 8·4 per cent. of carbonic acid, and if this had been about 4 to 5 per cent., as usual, the consumption of anthracite would have been proportionately less. Further trials of the engine at 41·7 brake HP. and 50 brake HP. were made, to prove its maximum power, but the fuel-consumption at those powers was not measured.

5. *Tewkesbury.*—At this place there is a Fielding and Platt engine, driving factory machinery and a dynamo supplying arc- and glow-lamps. The engine has been running satisfactorily for about 9 months, but a brake-test has not been made. An indicator diagram is given in Fig. 16, Plate 2.

6. *Uxbridge* (February, 1892). There are two 15-HP. nominal

Atkinson gas-engines and a Dowson plant at the Uxbridge Waterworks; and one of these engines was tested on behalf of the Rural Sanitary Authority by Mr. J. Tomlinson, late President Inst. M.E. His report was published in the *Engineer* of the 12th February, 1892. The general results show that the consumption of fuel was 1·067 lb. per I.HP., and 1·66 lb. per water HP. per hour. Mr. Tomlinson remarks, "To the best of my belief, this is the lowest fuel-consumption that has ever been obtained for any description of motor, more especially when it is considered that the engine was only giving 16·705 I.HP., and not more than three-quarters of what it was capable of doing." Fig. 17, Plate 2, shows an indicator diagram.

7. *Kilmarnock.*—Messrs. Dick, Kerr & Co. have made brake-tests for the Author of two of their double-acting engines worked with gas, with the following results:

—	14 HP. (Nominal).	25 HP. (Nominal).
Revolutions per minute	180	160
Explosions per minute	170	152
Mean effective pressure	57 lbs.	58·6 lbs.
Indicated HP.	36·69	75·4
Brake HP.	30·2	62·9
Mechanical efficiency	82·2 per cent.	83·5 per cent.

An indicator diagram of the 25-HP. engine is given in Fig. 18, Plate 2.

8. *Openshaw.*—Messrs. Crossley have also made a special brake-test of one of their single-cylinder 30 HP. (nominal) engines worked with Dowson gas, with the following results:—

Circumference at centre of brake-rope	22·77 feet.
Reading of spring-balance	690 lbs.
Net weight at end of Prony-brake, to be deducted from spring-balance reading	56 „
Revolutions per minute	160
Mean pressure of diagrams	74 „
Indicated HP.	81·4
Brake HP.	70
Mechanical efficiency of engine	86 per cent.

Fig. 21, Plate 2, gives an indicator diagram of this engine.

9. *Smethwick.*—Messrs. Tangye have built the largest single-cylinder engine produced up to the present time; and they give the following results of working with the Author's gas made from anthracite:—

—	25 HP. (Nominal).	35 HP. (Nominal).
Diameter of cylinder	15 inches	18 inches
Stroke	22 „	24 „
Revolutions per minute	160	160
Mean pressure of diagrams	80·2 lbs.	81·4 lbs.
Indicated HP.	63·1	100·4
Brake HP.	54·3	86·4
Mechanical efficiency	86 per cent.	86 per cent.
Consumption of anthracite per brake HP.	1 lb.	1 lb.

Fig. 22, Plate 2, represents an indicator diagram of this engine.

The foregoing particulars are summarised in Appendix A, and the Author has thought well to enter thus fully into the performance of engines actually working, as he believes that some engineers who have not tried large gas-engines are wrongly under the impression that their mechanical efficiency is low when working with generator-gas. He trusts, however, that the data which he has now been able to furnish regarding a variety of engines will help to dispel this illusion. It is quite true that the gas-engines now made cannot develop more than their normal maximum, whereas with steam-engines a certain increase of power can be obtained by raising the boiler-pressure; but there is no reason that the large gas-engine, as well as the small one, should not have a mechanical efficiency of 85 per cent. when in good order, and when working with generator-gas of good quality. As regards the best fuel for generator-gas, it must be assumed for the present that bituminous coal is not applicable to engine requirements. Many attempts have been made in this direction, but all have failed because the tarry vapours carried forward by the gas clog the valves, piston, &c. The best fuel is anthracite, as it yields no tar, and fulfils other conditions favourable to the production of good gas. Where anthracite is too dear, coke should be used, but it must be of fairly good quality, as much clinker interferes with the proper working of the plant. On the other hand, the coke for the generator should not be large, pieces about ¾-inch to 1-inch cube being best. If, therefore, the consumer is obliged to

buy large coke, he must break it to the size required. To meet these requirements, the Author suggests that the small coke of the gas-works yard should be washed to remove dirt, small coal, and other impurities; and he is of opinion that, when so treated, it could be sold profitably for less than the price of local steam-coal. In London and other important centres, there are already several users of anthracite who would gladly adopt coke if it could be obtained of suitable size and quality, and at a favourable price. It is hoped, therefore, that, as a new field of enterprise is opening up, the gas companies will give the matter attention.

There are many points in favour of gas-power, compared with steam-power, and the Author thinks that those who have taken part in its recent development cannot but feel gratified and encouraged by the progress made. All who are conversant with the leading gas-engines in use know that they have been greatly improved and simplified during the last four or five years. The consumption of gas per HP. has been sensibly reduced, there are now no troublesome slide-valves to keep in order, the noise from the exhausts has been overcome (a point of importance in large engines), self-starters are being introduced, and in other ways practical difficulties have to a great extent been overcome. Where there are accumulators, self-starters are not necessary, as the dynamo can then be used as a motor for starting the engine. Admirable results have undoubtedly been obtained from gas-engines working with the Otto cycle; but, notwithstanding this, the Author is of opinion that with engines of large size, the results would be still better if the cycle were altered, and he considers this especially desirable when generator-gas is used. In the first place, it should be remembered that an engine working with the Otto cycle cannot take in gas more frequently than every fourth stroke, and consequently each charge must be strong enough to drive the engine and its maximum load during four strokes; it follows, therefore, that when the charge is fired, the shock to the engine is four times as great as it would be if one-fourth the charge were exploded at every stroke. This great impulse not only causes a sudden increase in speed, but it also necessitates stronger, and therefore more expensive, working parts than in a steam-engine. All the larger sizes of gas-engines used for electric lighting have two parallel cylinders, or two cylinders end to end, so as to halve the intervals between the impulses. This tends to steady running, but it cannot be said to be an economical arrangement; as the engine is rendered more complicated and more costly to

construct, and the principal working parts of each cylinder must be able to withstand the stresses produced by a 4-stroke charge. The Author's belief is that, sooner or later, means will be found to work a compression-engine with an impulse at every stroke. This may involve an auxiliary pump, and consequently an increase in the friction of the engine; but, if cheap fuel-gas is used, this is a small matter compared with ensuring uniformity of speed, and reducing the stresses on the engine; besides this, there are other compensating advantages. An important point is that, to secure the greatest advantage to an engine working with generator-gas, the charge of gas and air should not be diluted with residual products from a previous charge; but it is well known that in the Otto cycle each new charge of gas is diluted with a considerable portion of residual products, as well as with an excess of air. This is claimed as an advantage, as it is supposed to prevent all the gas from being fired at the beginning of the stroke, so that the pressure may be maintained and the shocks be less severe. For such a strong combustible as ordinary illuminating-gas, containing some 52 per cent. of hydrogen, 35 per cent. of marsh gas, and 4 per cent. of olefiant-gas, this precaution is indeed said to be necessary. It may be so, but the Author is inclined to think that the real merit of the Otto cycle lies not so much in the dilution of the gas with spent products of combustion, as in the engine being able to draw in, compress and fire the charge in one, the same, cylinder.

Mr. Atkinson has informed the Author that he made some tests with a "Cycle" gas-engine, to determine whether or not it was desirable, when working with ordinary town-gas, to scavenge out all, or a small portion only, of the burnt gases. He had a connecting-rod that could be fixed to two different centres, one capable of driving out all the products of combustion, and the other leaving a space equal to about 30 per cent. of that occupied by the charge of gas and air. In this simple way, he found that in the same engine, and with similar gas, the consumption of the latter was about 25·7 cubic feet per brake HP. per hour, when the products were not scavenged out, and only 22·11 cubic feet when all were driven out with the exception of so much as remained in the clearance space between the end of the piston and the end of the cylinder, and in the valve-seatings, etc. This saving of 3·59 cubic feet per brake HP. per hour is equal to nearly 14 per cent. of the total cost of gas used. The Author is not prepared to say that, with the Otto cycle, there are not compensating advantages when town-gas is used for small

engines; but he knows that with an engine of this type, of any size, the indicated power can be increased 30 or 40 per cent. by scavenging out the products. He thinks, therefore, that for large engines, the cycle should be altered even for town-gas. Reverting to gas such as that made in the Dowson apparatus, its explosive force is as 1 : 3·8 compared with 16 candle-power gas,[1] and it is necessary to introduce about four times more of the weaker gas into the cylinder to develop the same power as with the town-gas. The real trouble, then, is not so much to prevent excessively high explosive effects, as to obtain them high enough for the efficient working of the engine. All generator-gas contains a large proportion of nitrogen, and some carbonic acid; and, if it is remembered that about four-fifths of every volume of air admitted into the cylinder of an engine consists of nitrogen, it is not difficult to imagine that it is no easy matter for individual molecules of oxygen to come into contact with the molecules of hydrogen and carbonic oxide. It is not possible to show in a diagram what actually occurs during the admission and compression of a charge of gas and air; but Fig. 22, Plate 1, indicates the relative proportions of the air, gas, and products of combustion that have to be mixed together. Without reference to the influence of the residual products, it is as though there were two contending parties in the charge of gas and air, four-fifths of one party endeavouring to prevent the remaining fifth from joining half the members of the other party, the other half of which is opposed to the union. When the charge of gas and air enters the cylinder, it is mixed with a considerable volume of residual products, and the combination of the oxygen with the combustible gases is rendered still more difficult. Apart from these difficulties, there remains the fact that carbonic oxide is slower to ignite than hydrogen, doubtless because the carbon has already partially satisfied its affinity for oxygen. Hence, more than half the combustible constituents of generator-gas are inherently slow to ignite, and, as this slowness of ignition is made worse by the presence of residual products, it is necessary to use a higher compression for a charge of generator-gas than for ordinary illuminating-gas, so as to bring the molecules closer together.

All this tends to show that generator-gas, or any comparatively weak form of gas, should not be diluted with residual products; and that no more air should be introduced than is

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[1] See "Cheap Gas for Motive-Power," Minutes of Proceedings Inst. C.E., vol. lxxiii. pp. 311 *et seq.*

necessary for the complete combustion of the charge. It should also be remembered that, when the products of combustion are scavenged out, it is not possible to have an explosion of greater energy than that required to develop the maximum power which the engine is intended to give. But with the Otto cycle, if from any cause the explosive charge is not fired, there is a still stronger charge to fire after the next intake of gas, as some of the products of combustion from the last charge fired will be displaced by new gas and air. In practice, therefore, after a miss-fire, the explosive force is often excessive. This could not occur if the products were always removed after each explosion, and, as less severe stresses would then have to be provided against, some parts of the engine could be lightened. Again the mixture of gas and air entering the cylinder is heated and expanded by the products of combustion from the previous explosion, so that the strength of each charge is somewhat diminished; and attention has been called to this by Professors Ayrton and Perry.[1] A further point is, that if a weak charge enters the cylinder, it may burn so slowly that part of the flame may remain in the Otto compression-chamber after the exhaust, and pre-ignite the next charge. This, again, would be impossible if all the hot products and flame were scavenged out, especially if a little air were admitted in front of the new charge. The Author drew attention to the points he is now raising in a Paper read before the British Association in 1888,[2] and he then expressed the hope that they would be considered. Up to the present time, however, all gas-engines have been designed for town-gas, and the makers have not thought it worth while to make special engines for generator-gas. In the "Cycle" engine, nearly all the products of combustion are exhausted, whether town-gas or generator-gas is used; and it has been seen that the 15-HP. engine at Uxbridge gives the lowest fuel-consumption ever recorded for an engine of that size. Certain mechanical difficulties have prevented the construction of larger engines of this type, but those already made seem to the Author to confirm his views about the advantage of removing the residual products. As regards other makers, so long as they were engaged on engines of small size, it was natural that they should not pay much attention to the special treatment required for generator-gas. But large engines are now made, and as they can only be worked

[1] "The Gas-Engine Indicator Diagram," *Philosophical Magazine*, July, 1884, p. 60.

[2] "Gaseous Fuel." Report of the British Association, 1888, p. 865.

economically with generator-gas, the Author thinks that the time has come for special attention to be paid to all the conditions necessary for obtaining the best results possible with gas of that kind. Large engines should be designed for the cheap fuel-gas, and should not be made for town-gas which is too costly to use, and then be worked with generator-gas as a make-shift, involving a loss of 10 per cent. of the maximum power that might be attained with gas too costly to use. Messrs. Crossley, more than any other makers, have developed the use of gas-engines in this country, and at the same time they have done much to advance the use of the Dowson gas. It is, in fact, chiefly due to them that such excellent results as those referred to have been obtained; and, in putting forward his present views, the Author hopes it will be understood that he does not seek to detract from the merit of what has been done, but that he merely wishes to draw attention to the direction in which still further improvements may be sought. He may not be entirely correct in his views, and all he desires is that they may be thoroughly sifted. Moreover, he thinks that the very fact that improvements can probably be made, is favourable to the prospects of gas-power generally. A fuel consumption of about $\frac{3}{4}$ lb. per I.HP. has been obtained with engines having certain drawbacks, and not specially designed for generator-gas; it is therefore reasonable to suppose that still better results will follow when the best possible conditions for the use of generator-gas have been complied with. The gas-engine, although only the grandchild, so to speak, of the steam-engine, is already able to convert more of its heat-energy into work than its predecessor; the steam-engine has been improved nearly as far as possible, but the internal combustion gas-engine can, undoubtedly, be improved, and, as the late Professor Fleeming Jenkin remarked, in his lecture on "Gas- and Caloric-Engines:"[1] "Since theory shows that it is possible to increase the efficiency of the actual gas-engine two- or even three-fold, then the conclusion seems irresistible that gas-engines will ultimately supplant the steam-engine."

A good non-condensing compound steam-engine of 150 to 200 I.HP. consumes $2\frac{1}{2}$ lbs. to 3 lbs. of coal per I.HP. per hour in average work, including the waste in the boiler when the engine is not working. Supposing, however, that its fuel-consumption could be brought down to 2 lbs. per I.HP. per hour, this would still be more than double the average consumption of a gas-engine of the same power. The saving in working-

[1] "Heat in its Mechanical Applications."—Inst. C.E., Sess. 1883-84, p. 131.

cost is therefore reduced by at least 50 per cent., so that a steam-engine indicating 150 IHP. and working 60 hours per week for 50 weeks, would require 400 tons a year (at 2 lbs. per IHP.), while a gas-engine would require less than 200 tons of anthracite, or about 265 tons of coke. Beyond this, there is the important saving before referred to, when an engine is working with less than its full load. Apart from the economy of gas-power, it is also important to realize that, as it requires only one-half or one-third of the quantity of coal needed for a steam-engine, the quantity of carbonic acid discharged into the air will be similarly reduced, and there can be no smoke. Further, the average consumption of water in steam-engines is about 30 lbs. to 40 lbs. per I.IHP. per hour, and nearly the whole of this is discharged into the air, in addition to the products of combustion. The Author has ascertained from several leading coal-merchants that the consumption of coal for steam-power, in the London district, is over 5,000,000 tons per annum, exclusive of that used on the railways. Assuming that three-fourths of this are burnt in the daytime, there is a consumption of about 1,500 tons of coal per working hour for steam-power, and, assuming that this contains an average of only 80 per cent. of carbon, it represents about 4,400 tons, or something like 80,000,000 cubic feet of carbonic acid per hour—to say nothing of carbonic oxide, sulphurous acid, and smoky hydro-carbons. If an average of[1] 5 lbs. of coal per IHP. per hour be assumed, there is a total of 672,000 IHP.-hours, and allowing an average of only 30 lbs. of water per IHP., there are 9,000 tons, or something like 400,000,000 cubic feet of steam discharged into the air every hour. It is not too much to suppose that the aggregate horse-power used in central-stations in the London district is not less than 20,000. If, then, an average consumption of only 3 lbs. of coal and 25 lbs. of water per IHP. per hour be assumed, there will be about 99 tons, or about 1,750,000 cubic feet, of carbonic acid, and about 223 tons, or about 10,000,000 cubic feet, of steam discharged into the atmosphere of the Metropolis every hour of maximum output, from electric-light stations alone. The fuel consumption is actually much greater, and it seems to the Author that, when these facts are realized, the question will arise, sooner or later, whether such enormous volumes of steam and carbonic acid are to be sent into the air,

[1] The Author has assumed 3 lbs. of coal and 25 lbs. of water per IHP. per hour for high-class engines, but, as a general average, not less than 5 lbs. of coal and 30 lbs. of water should be assumed.

regardless of the consequences to the inhabitants. Without adventitious circumstances, the rainfall of London and other great cities is already excessive, and the air is highly charged with moisture; it is therefore no trifling matter to have such immense volumes of condensed steam added to it. With gas-power derived from generator-gas, there is not more than half the coal to burn, and, therefore, only half the quantity of carbonic acid to be given off. The steam evolved from the oxidation of the hydrogen amounts to about 13½ cubic feet, or about 0·6 lb., per indicated HP. per hour, *i.e.*, about 2 per cent. only of that required for a steam-engine using 25 lbs. per HP. With gas-power, therefore, the vast clouds of oily, dirty carbonic acid and aqueous vapour can certainly be enormously reduced.

Estimates have been made on several occasions to compare the illumination produced electrically, and by gas-light, from a given weight of coal; but such estimates are misleading, as they neglect to take account of the fact that in gas-works a large proportion of the coal is converted into coke and other marketable products, and not into gas; whereas in an electrical plant, all the coal is burnt, and no by-products are recovered. Assuming that a ton of coal yields 9,500 cubic feet of gas and 1,500 lbs. of coke, and that 27 per cent. of this coke is burnt in the furnace under the retorts, there is an actual consumption of 1,140 lbs. of fuel to produce 9,500 cubic feet of gas—or, say, 8·3 cubic feet of gas, or 26·5 candle-power, per pound of fuel. This compares very unfavourably with the figures given for the electric light produced from 1 lb. of coal with a gas-engine; but the Author sees little practical advantage in making such a comparison, as the two systems are worked on a totally different basis, and as the fuel-consumption in either case is by no means the only cost. A more correct basis of comparison is that adopted by the German Continental Gas Company, at Dessau. They determined the quantity of gas required to give a certain candle-power in the ordinary way, and ascertained the cost of this after allowing for the sale of residual products. They then measured, during several months, the quantity of gas consumed in gas-engines to yield the same amount of light electrically in glow-lamps. The general result shows a saving of about 50 per cent. in favour of producing light electrically, and such a result, based on trials extending over a long period, is undoubtedly of importance. It would now appear that gas companies can with advantage establish small electrical stations in the heart of crowded neighbourhoods, and not only add to the day-consumption and proportionally reduce the night-consumption

of gas, but can retain many consumers who would otherwise be served by independent companies. Another important consideration is the possibility of working stations not belonging to a gas-company with engines driven by town-gas, instead of using steam-power. It has been seen that at Dessau, where accumulators are used in parallel, the consumption of gas is 39 cubic feet per kilowatt generated, and, at 2*s.* 6*d.* per 1,000 cubic feet, the cost is 1·17*d.* It has also been seen that, where accumulators are not used, the average consumption of gas is 47 cubic feet, and the cost of this, at 2*s.* 6*d.* per 1,000 cubic feet, is 1·41*d.* Assuming that with steam-power, without accumulators, the average consumption of coal is 10 lbs. at 15*s.* a ton per kilowatt, the cost is 0·08*d.*; and to this should be added the firemen's wages, cost of removing ashes, insurance, interest on cost of boiler, chimney, &c., not required. It is probable, therefore, that, in many cases, the working-expenses will be less with town-gas than with steam. Besides this, the capital outlay will be reduced, as there will be no boiler, and the ground space it occupies can be saved, but, above all, the gas-holder at the gas-works will provide a sufficient reserve of gas to meet any possible fluctuations in the output of current required, and so do away with the necessity for storing electricity to any great extent.

There remains the alternative of having a gas-plant for generator-gas at the central-station, and there again the gas-companies can choose between local stations served with ordinary illuminating-gas, and a central-station at the gas-works, worked with generator-gas made from coke. In the case of an independent company working the electrical station, the gas-companies are still interested in the question, as they can supply coke to be used in the generators.

The following is a summary of the leading points urged by the Author:

1. When town-gas is used for driving the engines of an electrical station, the consumption is about 50 per cent. less than the volume of gas required to give the same amount of light in ordinary burners.
2. When town-gas is used, no boiler and no fire-men are required, and there are no ashes to remove; less ground space is needed; no accumulators are required, except such as may be necessary to equalise the load of the engines, and to provide for a small amount of storage. The engines can be worked in the most crowded districts, close to where the lights are required, and where boilers are not allowed.

3. When generator-gas is used, the consumption of fuel under a full load can be at least 50 per cent. less than with steam-power; and the loss due to steam-boilers not fully worked can be almost entirely avoided.

With these points in view, the Author feels justified in saying that the use of gas-power has certain marked advantages compared with steam-power, and that the subject is worthy of careful consideration. It is not possible for a steam-engine to convert as much of the energy of the fuel into work as a gas-engine; it is not possible for a steam-engine and boiler to work with so low a fuel-consumption per horse-power as a gas-engine driven with generator-gas; nor is it possible for a steam-boiler to meet the requirements of a central-station without serious waste of fuel, which can nearly all be avoided with a gas-generator. The enormous volume of exhaust steam and products of combustion inherent in the working of a steam-power plant, is reduced by fully 90 per cent. when gas-power is used. These and the other points referred to in the Paper show that much progress is being made, and that if gas-companies, electricians and engine-makers will combine to meet the varying conditions of an electrical station, there is good reason to believe that, in the words of the late Professor Fleeming Jenkin, "the internal combustion gas-engine must command a brilliant future."

The Paper is accompanied by three tracings, from which Plates 1 and 2 have been prepared.

APPENDIXES.

APPENDIX A.

Fuel-Consumption of Engines Worked with Dowson Gas.

—	Locality.	Type of Engine.	Number of Indicator Diagram. Plate 2.	HP. (Indicated)	HP. (Brake).	Fuel Consumed.		Authority.
						Per Indicated HP. Working Hour.	Per Brake HP. Working Hour.	
						Lb.	Lb.	
1	Newtown . .	Crossley.	5, 6, 7	..	199	..	1·23	Severn Tweed Company.
2	Godalming . .	,,	..	210	..	1·0	..	Spicer & Company.
3	Halifax . . .	,,	10	170	..	1·4 (coke)	..	Carter & Company.
4	Chelsea . . .	,,	3, 4	118·7	..	0·762	..	J. E. Dowson.
5	Rouen . . .	Delamare-Debouttéville.	11, 12	31	25	0·92	1·15	E. Delamare.
6	,, . . .	,,	13, 14	111·9	76·8	0·90	1·34	A. Witz.
7	Deutz . . .	Otto.	15	..	52·25	..	1·67	K. Tiechmann and F. Böcking.
8	Nürnberg . .	,,	..	..	30	..	1·94	P. Beck.
9	Canale . . .	,,	..	..	36·45	..	1·9	Experts appointed by Court of Turin.
10	Uxbridge . .	Atkinson.	17	16·7	..	1·067	..	J. Tomlinson.
11	Kilmarnock .	Griffin.	18	75·4	62·9	..	..	Dick Kerr & Company.
12	Openshaw . .	Crossley.	21	81·4	70·0	..	..	Crossley Brothers.
13	Schwabing . .	Otto.	..	..	60	..	1·54	F. Uppenborn.
14	Longpont . .	Crossley.	20	42·5	..	1·2	..	J. & O. G. Pierson.
15	Smethwick .	Tangye.	..	100·4	86·4	0·86	1·0	Tangyes, Limited.

APPENDIX B.

Report on a Trial of 60-HP. (Nominal) Crossley Engine at Chelsea by the Author.

At the normal speed of 160 revolutions per minute, the maximum power of the engine was believed to be about 170 I.HP., whereas the greatest load which could be put on it at the time of the trial was estimated to be about a third less than the maximum. The engine had two cylinders; and to determine the actual HP. developed during the trial, I had a separate counter worked by the gas-valve of each cylinder, so as to count the exact number of explosions in each. There was also a counter on the crank-shaft. The engine had been doing regular work about three months, and, believing that all was in fair working order, I rehearsed the proposed trial, so as to be sure of having all necessary observations made, and so as to check the results of the final trial. The latter was made on 5th February, 1892, and the general results may be summed up as follows:—

Nominal power of engine . . . 60 HP.
Diameter of cylinders . . . . 17 inches.
Length of stroke . . . . . 2 feet.
Duration of trial . . . . . 8 hours (9·40 A.M. to 5·40 P.M.)
Total revolutions of crank-shaft during trial . . 74,751 = 155·73 per minute.
„ explosions in left cylinder . . . . . 25,908 = 53·975 „ „
„ „ „ right cylinder . . . . 26,619 = 55·456 „ „

	Left Cylinder.	Right Cylinder.	Both Cylinders.
Mean pressure of indicator diagrams[1]	79·9	77·9	78·9
Mean indicated HP. during trial	59·3	59·4	118·7
Maximum indicated HP. with speed of 160 . . .	..	..	173·6

Mean temperature of gas in bags near engine . . . 67° F.
„ „ „ air to engine . . . . . 50° „
„ „ „ water-overflow from left cylinder . 125° „
„ „ „ „ „ „ right cylinder. 119° „
„ „ „ feed-water of boiler . . . . . 75° „
Mean pressure of gas in gas-holder. . . . . 1⅝ inch water.
„ „ „ steam in boiler . . . . . 48 lbs.

Levels of water in boiler, of fires in boiler and generator, and of gas-holder, were all the same at the end of the trial as at the beginning.

[1] Eighteen diagrams were taken on each cylinder, at intervals of about 30 minutes. Each diagram gives the curves of ten consecutive strokes of the indicator. The same indicator and spring were used for both cylinders. The 100-lb. spring used was a new one, tested by Elliott Brothers, who also supplied the counters.

Anthracite [1] consumed in generator during trial	584 lbs.
Coke [2] „ „ boiler to get up steam before trial	30 lbs.
Coke consumed in boiler during trial	140 lbs.
Anthracite consumed during trial . . .	0·615 lb. per I.HP. working hour.
Coke „ „ „ . . .	0·147 „ „ „ „ „
Total	0·762 lb. per I.HP. working hour.
Anthracite put in generator on morning after trial to make up for loss during 9 night hours . . . . . 56 lbs.	0·058 lb. per I. HP. working hour.
Anthracite put in generator on following morning after raking out clinkers, etc., 50 lbs.	0·053 lb. „ „
Total loss during night and after clinkering 106 lbs.	0·111 lb. „ „
Total consumption of anthracite and coke during trial and following night . .	0·873 lb. „ „

Gas consumed [3] at rate of about 63 cubic feet per I.HP. per hour.

Anthracite consumed during trial, about 10 lbs. } Per 1,000 cubic feet
Anthracite and coke consumed during trial, about 12 lbs. } of gas made.

Water [4] used for cooling the engine	600 gallons per hour	= 50·5 lbs.	per I.HP. per hour.
Water used for boiler .	10 „ „ „	= 0·8 „	„ „ „ „
Water used for cleaning gas	14 „ „ „	= 1·1 „	„ „ „ „
Total water used during trial	624 „ „ „	= 52·4 „	„ „ „ „

Total water used for gas-making . . . . { 3·2 gallons per 1000 cubic feet of gas made.

Oil used for cylinders during trial . . . . 1½ pint at 2*s.* 9*d.* per gallon.
„ „ bearings „ „ . . . . 1½ pint at 1*s.* 4*d.* „ „
Coal-gas [5] used for heating ignition tubes . . 4½ cubic feet per hour.

Machines worked during trial.

- 1 pair stones (4 feet diameter)
- 13 „ rolls (250 revolutions)
- 4 „ disks (600 revolutions)
- 14 ordinary silks
- 7 centrifugal silks
- 4 purifiers
- 24 elevators.
- 2 exhaust fans.
- sundry conveyors.
- pump.
- shafting, etc.

[1] Anthracite used was the usual kind from the Gwaun Cae Gurwen Colliery Company, Limited.

[2] Coke from Gas-Light and Coke Company.

[3] Rate of gas consumed was measured by shutting the inlet of gas-holder and timing the fall of the holder through 6 feet, while the engine was working.

[4] All the water used was pumped up from the river by the engine, and run to waste. Usually the water used for cooling an engine flows to and from an overhead tank.

[5] Coal-gas was used for this purpose, because Dowson gas could not be taken from the main supplying the engine, and there was no separate outlet from the gas-holder.

APPENDIX C.

Gas-Power at the Cambrian Mills, Newtown, Montgomeryshire.

Table I.—*Showing the Result of Working Six Days (56 Hours) with Dowson Gas, made from Welsh Anthracite, the Data being Furnished by the Severn Tweed Company, Limited.*

Number of Section.	Nominal HP. of Engine.	Approximate Maximum Brake HP. of Engine.	Approximate Brake HP. used for Machines and Shafting during Trial.	Brake HP. Hours during Trial.	Fuel consumed.			Cost of Fuel.			Remarks.
					Anthracite for Generator.	Slack for Boiler.	Total per Brake HP. per Hour.	Anthracite per Ton.	Slack per Ton.	Total per Brake HP. per Hour.	
1 and 4	60	128	96·03	5,378	Lbs.	Lbs.	Lbs.	*s.* *d.*	*s.* *d.*	*d.*	The boiler was partly fired with anthracite cinders, &c., which fell through the generator grate-bars.
2	40	73	72·39	4,054	13,416	336	1·23	19 10	9 6	0·13	
3	40	73	27·00	1,515							
Hoists	4	5½	3·57	200							
	144	279½	198·99	11,147							

Table II.—*Showing the Result of Working Six Days (56 Hours) with Dowson Gas made from Ordinary Gas Coke from the Gas Works, Wellington, the Data being Furnished by the Severn Tweed Company, Limited.*

Number of Section.	Nominal HP. of Engine.	Approximate Maximum Brake HP. of Engine.	Approximate Brake HP. used for Machines and Shafting during Trial.	Brake HP. Hours during Trial.	Fuel consumed.			Cost of Fuel.			Remarks.
					Coke for Generator.	Slack for Boiler.	Total per Brake HP. per Hour.	Coke per Ton	Slack per Ton.	Total per Brake HP. per Hour.	
1 and 4	60	128	89·46	5,010	Lbs.	Lbs.	Lbs.	*s.*	*s.* *d.*	*d.*	The coke was not of good quality. There was no residue from the coke in the generator, which could be used in the boiler.
2	40	73	66·12	3,703	16,645	1,568	1·73	15	9 6	0·135	
3	40	73	28·49	1,595							
Hoists	4	5½	3·57	200							
	144	279½	187·64	10,508							

APPENDIX C—*continued.*

TABLE III.—*Showing Machines used and Horse-power required in each Section.*

Section No. 1.		Section No. 2.		Section No. 3.		Section No. 4.	
Description of Machine.	Approximate Brake HP. required.	Description of Machine.	Approximate Brake HP. required.	Description of Machine.	Approximate Brake HP. required.	Description of Machine.	Approximate Brake HP. required.
Blackman fan . . .	2·50	6 twisting-machines .	18·00	40 fast looms . . .	19·00	5 fulling-machines .	15·00
Wool-drying machine	3·25	12 mules	24·00	47 slow „ . . .	8·00	3 washing „ .	3·00
Shaker	0·50	Warp hank machine .	1·00	4 Sowden looms . .	0·50	2 hydros	1·00
Burring machine . .	3·50	Reel „ „ .	1·00	6 Bradford „ . .	0·50	Wool-scourer . . .	3·00
New Willey . . .	2·00	5 sets of carding-machines . . .	30·00	4 winding-machines.	4·00	Stocks	0·50
Old „ . . .	2·00	Shafting, &c. . . .	6·00	Shafting	8·00	Shearing-machine, &c.	5·00
Garnet machine . .	1·25					Tenter machine . .	6·00
8 sets of carding-engines	48·00					Shafting, &c. . . .	4·00
2 „ waste „	4·00						
6 mules.	12·00						
Shafting, &c. . . .	6·00						

At the time the trials were made the mill was not in full work, and the aggregate brake-power was estimated as closely as possible. The above figures include the fuel consumed during each night, when the engines were not working, and all other sources of waste from the start on Monday morning to the finish on Saturday afternoon.

APPENDIX D.

The undersigned on April 7, 1887, at the request of the Gas Motoren Fabrik of Deutz, and in the workshops of the same, made experiments respecting the power developed by, and the fuel consumption of, a 40-HP. motor worked by Dowson gas.

The gas is produced in a closed apparatus, and a steam-jet blower drives continually a mixture of super-heated steam and atmospheric air through a layer of glowing coal, whereby hydrogen and carbonic oxide are formed. The motor is horizontal, with twin cylinders, 340 millimetres in diameter, and 600 inches in stroke. The motor was worked with a brake, and the length of the brake-lever was 1·433 metre; the work therefore:—

$$N = \frac{2\,\Pi\,l\,n\,P}{60 \cdot 75} = \frac{2\,\Pi\,1 \cdot 433\,n\,P}{60 \cdot 75}$$

$$N = 0 \cdot 00200\,n\,P \text{ horse-power.}$$

After two hours' regular work without measurement, from eleven o'clock to one o'clock:—

The weight on the lever amounted to	P = 191 kilograms.
Revolutions, total	2 × 8,426.
Revolutions per minute	n = 140·4.
Effective horse-power	N = 53·63.

At one o'clock the brake-power was reduced, and, with a weight of P = 181 kilograms, from one o'clock to five o'clock 2 × 16,863 revolutions were made. Consequently, per minute, n = 140·5 revolutions, from which an effect of 50·86 HP. was given. At five o'clock the machine was stopped. It developed therefore:—

During 2 hours 53·63 horse-power	= 107·26	HP. hours.
During 4 hours 50·86 horse-power	= 203·44	„ „
Total . . .	310·70	„ „

The gas-generator was fed with anthracite coal in pieces of 13 to 25 millimetres in diameter, and the top of the fire was kept at the same height. The small boiler for the production of the super-heated steam was heated with gas-coke. The boiler was fed by a steam-pump, which took steam from the same boiler. The gas was cleaned by a scrubber and conducted through a gas-holder of 4·6 metres diameter. The gas-holder sank 2·085 metres from eleven o'clock to one o'clock, and remained from that time almost exactly at the same height. After stopping the engine, the holder was again, at 12 minutes past 5, filled to its original height. The fuel was consumed as follows:—

—	From 11 A.M. to 1 P.M.	1 P.M. to 5.12 P.M.	11 A.M. to 5.12 P.M.
	Kilograms.	Kilograms.	Kilograms.
Anthracite in the generator . .	74	136·5	210·5
Coke in the boiler	8	19	27
Total fuel	82	155·5	237·5
Feed-water.	50	118	168

With a total fuel-consumption of 237·5 kilograms, the above total effect of 310·7 HP.-hours was attained; therefore the consumption of fuel amounts to 0·7644 kilogram per HP.-hour, of which 0·677 kilogram was anthracite used in the generator, and 0·0869 kilogram was gas-coke consumed in the boiler. The consumption of steam for the production of gas and feeding the boiler amounted to 0·54 kilogram per HP.-hour, being 6·22 times greater than the weight of coke used in the boiler, the mean pressure of the steam amounting to 3·65 atmospheres.

(Signed) K. Tiechmann.
Fr. Böcking.

Stuttgart, April 19, 1887.

APPENDIX E.

Translation of Report made by Mr. P. Beck, on Trials of Otto Engine at Nürnberg.

The engine was made at Deutz, and was used in the brewery of Baron von Tucher for working refrigerators. The first trial was made on 12th December, 1888, with English anthracite in the Dowson gas-generator; and the second trial was made the following day with German anthracite.

—	First Trial.	Second Trial.
Brake HP. developed	30	30
Anthracite consumed in 5 hours 10 minutes	111 kilograms	..
Coke consumed in 5 hours 10 minutes . .	28 „	..
Anthracite consumed in 5 hours	..	113 kilograms
Coke consumed in 5 hours.	..	20 „
Anthracite consumed per brake HP. per hour	0·716 „	0·753 „
Coke consumed per brake HP. per hour . .	0·180 „	0·133 „
Total fuel consumed per brake HP. per hour	0·896 „	0·886 „
Cost of fuel „ „ „	2·96 pfenige	2·51 pfenige

APPENDIX F.

EXTRACTS FROM REPORT MADE BY EXPERTS TO HIGH COURT OF TURIN.

After examining all parts of the engine and gas-apparatus the trial began at 9.55 A.M., and was stopped at 5.55 P.M., on 9th January, 1890. During this time, the chemist (Mr. Monaco) took several samples of gas from the holder and from the engine-exhaust, for analysis afterwards. It was noticed that one workman was sufficient to work the gas-apparatus, and that his work was not onerous.

Anthracite consumed during 8 hours' trial . .	215	kilograms.
Coke „ „ „ . .	37	„
Total fuel	252	„

Length of brake-lever	2	metres.
Gross weight always on brake . . .	155	kilograms.
Tare of brake	63	„
Nett load on brake.	92	„
Revolutions of engine	140	per minute.
Brake HP. developed	35·95.	

[NOTE.—There was a pump attached to the engine for circulating water for cooling, and its work was estimated to be equal to 0·5 HP. The pump was working during the whole of the trial, and the 0·5 HP. was added to 35·95, thus making the total 36·45 brake HP.]

Anthracite consumed per brake HP. per hour . .	0·737	kilogram.
Coke „ „ „ . . .	0·127	„
Total fuel	0·864	„

On the following day (10th January), a further trial was made to determine the maximum HP. of engine, and the gas-generator was worked without drawing the fire left in it the previous day, and without even removing the clinkers and ashes. The gas made was good; and this proved that the generator could be worked several hours without any stoppage to clean the fire. The brake trial on this day, lasting three hours, showed that the total power developed, including the 0·5 HP. for pump was 42·2 brake HP. Towards the end of this trial, the engine was run at 50 brake HP.; and during this time the generator was able to make gas enough for the engine, although it was only intended to supply 40 HP.

The analyses made afterwards gave the following averages:—

(*a*) *Anthracite used in generator*:—

Carbon	92·90
Water	1·70
Ash	3·87
Sulphur	0·83

(*b*) *Gas taken from the gasholder :—*

Carbonic anhydride	8·40
Oxygen	0·90
Hydrogen	16·67
Carbonic oxide	27·50
Nitrogen	46·73
	100·20

(*c*) *Products of combustion from the engine exhaust :—*

Carbonic anhydride	9·08
Oxygen	15·04
Carbonic oxide	15·69
Nitrogen	60·19
	100·00

APPENDIX G.

Translation of abridged Report by Mr. F. Uppenborn.

Formerly Schwabing was lighted by oil-lamps, and about three years ago rival proposals were submitted to the Municipality for lighting with gas and electricity. After long and careful investigation, it was eventually decided to use electricity, and in October 1888 an order was given to Messrs. J. Einstein & Co. for the electrical apparatus, and to Messrs. Schur & Co. for the engineering plant required.

The installation was satisfactorily completed, and on February 14, 1889, the public lighting was commenced, and from that day to the date of the Report it has continued without interruption.

The motive-power is derived from a double-cylinder Otto engine, specified to work up to 40 HP. (effective), with fly-wheels and driving-pulleys on each side. The engine is driven by Dowson gas produced from German anthracite coal. Steam is produced in a little boiler in the corner of the gas-house, and is afterwards decomposed by passing through the red-hot fuel in the generator. Thence the gas passes through the hydraulic box and scrubbers into the gasholder. From the latter there is a main to supply the cylinder of the engine with gas, and a separate small pipe for serving the flames which ignite the charge.

There is a countershaft near the ground-level, and two Müller dynamos are driven from this. Each dynamo gives 115 amperes per minute with a speed of 950, the electromotive force being 120 volts. The switches and resistances for each dynamo are fixed to the wall. The dynamos are fixed to sliding frames, so that the tension of the belts can be regulated.

There are 10 arc-lamps of 1,000 candle-power (nominal) each, 30 glow-lamps of 32 candle-power each, and 170 glow-lamps of 16 candle-power each. All the wires are carried overhead, as for such a district it would have been too expensive to place them underground.

The whole plant was tested, and gave the following results. When the engine was loaded, the variations of speed were under 1 per cent., and the light of the glow-lamps was practically constant. A brake-test of the engine showed it was actually capable of developing fully 60 HP. (effective). A brake trial showed that 600 grams of anthracite and 100 grams of coke were consumed per brake HP. per hour. The result of the combustion was as follows:—

0·6 kilogram of anthracite, at 7,600 calories . . .	4,560	calories.
0·1 „ coke „ 7,000 „	700	„
Total	5,260	„

From these figures it is easy to calculate the proportional value of working power. One HP. = 75 kilogram-metres per second. One HP-hour = 75 × 3,600 = 270,000 kilogram-metres = 636 calories. The expenditure $\frac{636}{5260}$ gives as a result 12 per cent. of the fuel consumed per HP. per hour.

It is estimated that if the engines had been worked with the town-gas of Munich, the cost would have been 12 pfennige (1½*d.*) per HP. per hour, and that with the Dowson gas it is 2·2 pfennige, or about 80 per cent. cheaper. It is further concluded that a large gas-engine driven by Dowson gas can compete successfully with a good steam-engine.

APPENDIX H.

REPORT TO THE AUTHOR BY MESSRS. ANDREWS AND PREECE, OF BRADFORD.

The construction of the works was begun at Easter last, and one engine was running with town-gas at Whitsuntide. There are three Stockport engines, each of 16 HP. nominal, a set of Dowson gas plant, and three special Preece dynamos of 300 lights each at 750 revolutions per minute. There are also 70 electric-power storage accumulators of 25 K type.

The whole of the machines are coupled in parallel and started consecutively, as the load is put on.

All the engines were set to work with town-gas early in July, and they are now running with Dowson gas.

A daily record is kept of all the readings taken, and of the fuel-consumption; and the following returns have been selected as representing two average weeks.

Week ending the 21st of August, 1892.

Kilowatts delivered	1,600	
Town-gas consumed	62,000	cubic feet.
Cost of gas at 3*s.* 3*d.* per 1,000 cubic feet . .	£9 19*s.* 0*d.*	
		d.
„ „ „ per kilowatt		1·50
„ „ labour „ „		0·45
„ „ oil and waste per kilowatt		0·015
„ „ water		0·03
Total cost with town-gas per kilowatt . . .		1·995

Week ending the 2nd of October, 1892.

Kilowatts delivered		1,800
Town-gas consumed		74,000 cubic feet.
Cost of gas at 3*s.* 3*d.* per 1,000 cubic feet.	£12 0*s.* 6*d.*	
		d.
„ „ „ per kilowatt		1·555
„ „ labour „		0·400
„ „ oil and waste per kilowatt		0·013
„ „ water „		0·035
Total cost with town-gas per kilowatt		2·003

These returns were taken under the usual working conditions, the load on the engines varying considerably.

The number of glow-lamps in use is equal to 1,600 of 8 candle-power; they actually consist of 8, 16, 32 and 50 candle-power each respectively. There are also 9 arc-lamps of 2,000 candle-power each.

In the week ending the 21st of August, the current varied each night from 5 to 350 amperes by 115 volts; and in the week ending the 2nd of October, from 5 to 450 amperes.

On the 22nd of October a test was made while the gas-engines were driven with Dowson gas, with the following results:—

Kilowatts generated	165 †
Anthracite consumed in generator	378 lbs.
Coke „ „ boiler	48 „
Total fuel consumed per kilowatt generated	2·58 lbs.
	d.
Cost of Dowson gas, including wages of fireman, fuel, &c., per kilowatt delivered	0·50
Labour, oil and waste, water, &c., as for town-gas	0·45
Total cost of Dowson gas per kilowatt-hour	0·95

The current varied from 5 to 200 amperes at 120 volts, and was less than in the previous trials, because several customers had contracted to have electric lights for the summer season only.

APPENDIX I.

TRANSLATION OF REPORT RECEIVED FROM MESSRS. J. & O. G. PIERSON, OF PARIS.

The trial was made on the 2nd of September, 1892, at the chateau of Mr. Say, at Longpont, in the south of France. There is a Gramme dynamo and a Crossley engine worked with gas made from anthracite in the Dowson apparatus. The current can be taken to 650 glow-lamps and one arc-lamp direct at 110 volts, or can be used to charge accumulators. There are 56 cells, which are able to serve the lamps during 8 hours, and when charging the cells the dynamo works at 120 to 130 volts, and gives 50 to 80 amperes.

The object of the trial was to determine the maximum HP. (effective) of the engine, and the consumption of fuel during several hours while the engine was fully loaded. Readings of the volt- and ampere-meters were taken at regular intervals, and are given in Table I below. Indicator diagrams (Fig. 20, Plate 2) were also taken on the engine; but no brake test was made. The maximum I.HP. was 46·5, and the mean I.HP. was 42·55. During the trial, part of the current was sent to the accumulators, and part of it to the lamps. The amperes given in the Table are in each case the sum of the readings given by the two ampere-meters.

The sum of all the watts observed is 547,124, and there were 29 observations, so that the average number of watts is consequently $\frac{547,124}{29}=18,870$.

The highest number of watts was 20,988 at 2.10 P.M.

As there was no counter on the engine, the revolutions were counted at intervals, and gave the following results:—

P.M.	Revolutions.	P.M.	Revolutions.
1.45	164	4.20	158
2.10	162	4.30	158
3.0	154	5.0	148
3.10	162	5.10	152
3.40	164		

The mean number of revolutions per minute was 158.

The mean pressures of the indicator diagrams are given in Table II.

The cylinder was 355 millimetres in diameter, and the stroke 560 millimetres.

The engine was started at 12.35, and stopped at 5.35, and during this time the fuel consumed was 111 kilos—91 kilos of anthracite and 20 kilos of coke. There was a stoppage of thirteen minutes, as explained in Table II, so that the engine was actually working 287 minutes. The fuel consumption was as follows:—

——	Anthracite.	Coke.	Total.
	Kilos.	Kilos.	Kilos.
Per minute	0·317	0·700	0·387
Per hour	19·020	4·200	23·220
Per kilowatt-hour	1·008	0·222	1·230
Per indicated HP. per hour	0·447	0·099	0·546

TABLE IV.

Time.	Volts.	Amperes.	Watts.	Remarks.
12.45	112	135	15,120	Started at 12.35.
1.0	115	182	20,930	
1.15	90	90	8,100*	* The engine was stopped because it was thought to be overheated, but it was afterwards found that it did not work well, because the gas-cock had been partially closed by mistake.
1.35	108	148	15,984	
1.40	110	175	19,250	
1.45	108	190	20,520	
1.50	104	170	17,680	
2.0	106	196	20,776	
2.10	106	198	20,988	
2.20	105	198	20,790	
2.30	105	183	19,215	
2.40	105	188	19,740	
2.50	105	188	19,740	
3.0	104	162	16,888	
3.10	105	186	19,530	
3.20	105	195	20,475	
3.30	105	186	19,530	
3.40	105	198	20,790	
3.50	105	198	20,790	
4.0	105	186	19,530	
4.10	105	186	19,530	
4.20	105	171	17,955	
4.30	105	186	19,530	
4.40	105	186	19,530	
4.50	105	181	19,005	
5.0	105	181	19,005	
5.10	104	176	18,304	
5.20	104	176	18,304	
5.30	105	182	19,635	

TABLE V.

Time.	Mean Pressure from Diagrams in Pounds per Square Inch.	Mean Pressure from Diagrams in Kilograms per Square Centimetre.
12.35		
1.0	64·8	4·555
2.0	66·4	4·668
2.10		
2.20	61·3	4·310
2.40	60·1	4·225
2.50	63·7	4·478
3.5	63·9	4·492
3.20	59·2	4·197
3.40		
3.50	62·4	4·387
4.10	60·9	4·281
4.30		
5.10		
5.30	59·7	4·197

APPENDIX J.

RESULTS OF TESTS MADE FOR THE AUTHOR BY MESSRS. LEA AND THORNBERRY, ELECTRICIANS, BIRMINGHAM.

1. ½ HP. (nominal), Crossley engine with dynamo A.

B. HP.	1·40
Output	506 watts.
Gas per hour	49·2 cubic feet, including ignition-burner.
Gas per brake HP.	35·2 cubic feet.
Gas per kilowatt	97·0 „

2. The same engine with dynamo B.

I. HP. 1·70 =	1,268 watts.
B. HP. 1·36 =	1,014 „
Mechanical efficiency of engine	0·80
Output	450 watts.
Efficiency of dynamo and belt	0·457
Gas per hour	46·2 cubic feet, including ignition-burner.
Gas per I. HP.	27·2 cubic feet.
Gas per brake HP.	34·0 „
Gas per kilowatt	102·6 „

3. The same engine with dynamo C.

B. HP. 1·348 =	1,005 watts.
Output	648 „
Efficiency of dynamo and belt	0·644
Gas per brake HP. as before.	34 cubic feet.
Gas per kilowatt	71·3 „

4. 2 HP. nominal, Crossley engine with dynamo D.

Gas per hour	65·4 cubic feet, including ignition-burner.
Output	1,173 watts.
Gas per kilowatt	55·6 cubic feet.

(Engine under control of governor.)

5. The same engine and dynamo, but the dynamo-pulley reduced so as to cause the engine to run more slowly, and to explode every time, with an output of 1,500 watts.

Gas per hour	77·2 cubic feet, including ignition-burner.
Output	1,500 watts.
Gas per kilowatt	51·4 cubic feet.

6. The same engine and dynamo, after wearing into better running order.

Gas per hour	79 cubic feet, including ignition-burner.
Output	1,550 watts.
Gas per kilowatt	51 cubic feet.

7. The same engine under a brake.

Revolutions per minute	140	
Brake HP. 2·77 =	2,066	watts.
Gas per hour	90·70	cubic feet, including ignition-burner.
Gas per brake HP.	32·74	cubic feet.
Gas per E. HP.	38	cubic feet in output of No. 6.
Efficiency of dynamo and belt	0·86	

8. 3½ HP. (nominal) Crossley engine and dynamo.

Gas per hour	130	cubic feet, including ignition-burner.
Output	2,260	watts.
Gas per kilowatt	57·5	cubic feet.

The comparison of 1, 2 and 3 is instructive, showing how dynamos vary in efficiency.

The comparison of 4 and 5 shows the advantage of running fully loaded instead of under governor control.

No. 8 had an iron dynamo pulley and a slack belt with considerable slip. Nos. 4, 5 and 6 had a wooden pulley and but little slip, although the belt was slack. This probably accounts for the difference between 57·5 and 51 cubic feet of gas per kilowatt, the dynamos being both excellent machines.

APPENDIX K.

RETURNS SENT BY MESSRS. CROSSLEY TO THE AUTHOR.

(*a*) 9 HP. (nominal) Crossley engine without accumulators at the Don Clothing Association, Manchester.

Schuckert dynamo. 16 arc-lamps of 500 candle-power each.

Cost per annum.

	£.	*s.*	*d.*
Gas for engine	38	18	11
Carbons	38	14	1
Repairs	3	0	0
Water	5	0	0
Attendance	26	0	0
Interest on plant at 10 per cent.	50	0	0
Total	161	13	0

(Number of working-hours not known.)

(*b*) 16 HP. (nominal) Crossley engine, with accumulators and Kapp dynamo, at Messrs. Tussaud & Sons' Exhibition.

Output	260 amperes × 115 volts.
Electrical HP.	40
Gas per kilowatt hour	50 cubic feet.

(*c*) 7 HP. (nominal) Crossley engine, with accumulators, at residence of Mr. Arthur Wilson, Grosvenor Place.

Output	50 amperes × 105 volts.
Electrical HP.	7
Gas per kilowatt-hour . .	60 cubic feet.

(Engines not working to full power.)

(*d*) 9 HP. (nominal) Crossley engine, with accumulators and Elwell-Parker dynamo, at Bank of England.

Output	65 amperes × 122 volts.
Electrical HP.	10
Gas per kilowatt-hour . .	40·5 cubic feet.

(*e*) E size high-speed Crossley engine, without accumulators, at offices of Messrs. Crossley, Openshaw.

Elwell-Parker 5-unit dynamo, and 100 lamps of 16 candle-power each.

Output	50 amperes × 102 volts.
Gas per hour	200 cubic feet.
„ „ lamp per hour	2 „ „

(*f*) 12 HP. (nominal) Crossley engine, without accumulators, at the Louvre Restaurant, Manchester.

Royce dynamo, and 200 lamps of 16 candle-power each.

Output	200 lamps at 100 volts.
Gas per hour	380 cubic feet.
„ „ lamp per hour . . .	1·9 „ „
„ „ kilowatt-hour . . .	38·0 „ „

(*g*) E size high-speed Crossley engine, without accumulators, in use by the Electrical Engineering Company of Ireland.

Output	40 amperes × 109 volts.
Gas per hour	195 cubic feet.
„ „ kilowatt-hour	44·7 „ „

(*h*) 9-HP. (nominal) Crossley engine, without accumulators, at the Art Gallery, Birmingham.

Chamberlain and Hookham dynamo, and 100 lamps of 16 candle-power each. The lamps are arranged in a ring, 7 feet diameter, with silvered glass reflectors. They replace a sun-burner which consumed 800 cubic feet per hour, and are said to give at least three times as much light on the pictures. Gas consumed for electric lamps, 270 cubic feet per hour.

(*i*) 4-HP. (nominal) Crossley engine, without accumulators, at 24 Poultry, E.C.

Started 4.16 P.M	Gas-meter 411,810 cubic feet.
Lights started at 4 h. 18′ 25″ P.M.	
At 5.1 P.M.	„ „ 411,920 „ „
„ 5.16 P.M.	„ „ 411,960 „ „
Load, 59 lamps of 16 candle-power each, at 100 volts.	
Gas per hour (not including ignition-burner) . .	150·0 cubic feet.
„ „ lamp per hour	2·56 cubic feet.
Average speed of engine during the run . . .	162 revolutions per minute, igniting every time.
Number of ignitions to drive engine	16 per minute.
„ „ „ „ and dynamo, without load	19 „ „

(*j*) 12-HP. (nominal) Crossley engine, with accumulators, at Messrs. Barclay's Bank.

One hour's run, from 11.30 to 12.30.

Gas-meter at 11.30	530,300 cubic feet.
„ „ 12.30	530.825 „ „
Output.	83·5 amperes × 101·5 volts.

Charging 106 cells, and serving lamps.

At 11.30	43 amperes to lamps, 40 amperes to cells.
„ 12.30	30 „ „ 54 „ „
„ 11.30	103 volts.
„ 12.30	100 „

[Could not give number of lamps, as they were continually being switched on and off.]

APPENDIX L.

Communication from Sir David Salomons to the Author.

Much depends whether a counter-shaft is used, the size of engine, and make as well as size of dynamo, also the quality of the gas; other matters also enter. I can give you my own working results with 15 candle-power gas here. The engines are Crossley's—14 HP (nominal) each. One is used at a time. A counter-shaft is used, and the friction load—all free—is 7 HP. Under these conditions we produce 100 amperes at 125 volts for a gas-consumption averaging 490 cubic feet—taken over many hours—per hour.

Discussion.

Mr. Hayter. Mr. HAYTER, President, said that it was now assumed that there must be antagonism between lighting by electricity and lighting by gas. That might be so, but he remembered the late Sir William Siemens asserted that, although, as time went on, lighting by electricity must in a greater or less degree supplant lighting by gas, yet, owing to the many uses to which gas could be applied besides lighting, its consumption would continue to increase. He believed that had been borne out by experience. What the reasons were he could not specify, but, be those what they might, the Author had at any rate shown that gas could render essential service in connection with electric lighting. That might to some extent tend to reconcile opposing interests. He was sure that the members would desire to express to the Author their thanks for his clear exposition of "gas-power for electric lighting."

Mr. Dowson. Mr. DOWSON desired to make a few remarks upon some of the diagrams referred to in the Paper, particularly those of Figs. 11 and 12, Plate 2. It would be observed that greater brake-power was developed with the irregular diagram than with that having an earlier and more regular ignition. The explanation given by the inventor of the engine was that, when there was a late ignition, the crank had proceeded further in its revolution, and there was then a quicker conversion of heat into work. He had not referred to the Clerk engine in the Paper, as he had no exact particulars of its working, but he had a satisfactory account in a letter from the engineer of the Kenilworth waterworks, where two 12-HP. Clerk engines were used. With regard to Fig. 2, Plate 1, he wished it to be understood that it showed the maximum ground-space required for the gas-plant. In case of need, it was possible to put the whole of the plant, with the exception of the gas-holder, under or over the engine-house, and, if necessary, the gas-holder could be at a considerable distance from the rest of the plant. The diagram showed engines with cylinders end-to-end, but, if preferred, they might be parallel. Referring to Fig. 23, he hoped no one would suspect him of trying his "'prentice hand" at some new atomic theory. He had merely attempted to show in a rough way the charge of gas and air flowing into the cylinder, and the products of combustion which would have to be mixed

with it in an Otto cylinder. The inner cone represented the generator-gas; and the outer cone represented air in the proportion 2 of air to 1 of gas. The dots represented the combustible part and the crosses the incombustible part of the generator-gas—the latter consisting of about 50 per cent. of combustible gas, the remainder being nitrogen and carbonic acid. The circles showed the oxygen in the air, and the crosses the nitrogen. The point he had tried to demonstrate was, that the mixture of the gas and the oxygen required for its combustion was already attended with considerable difficulty, and that, as the engine was at present worked, the charge had to be further diluted with residual products of combustion—rendering the combination of the gas with the oxygen still more difficult. Several schemes had been advanced in connection with that question. In the specification of a patent granted to Dr. Otto, dated the 4th January, 1881, these words occurred:—"The products of combustion do not materially interfere with the combustion of the following charge if the gas employed is of a very inflammable character, such as coal gas; but when gas of less inflammable character is used, such as carbonic oxide, it is of advantage to remove the said products more or less completely." In December, 1881, Mr. Crossley took out a patent in which he sought to aid the removal of the residual products by means of an exhaust-pump. Recently, the manager of the German Otto engine-works had thus expressed his opinion: "In all cases, and especially where weak gas is used, the expulsion of the products of combustion is an advantage; a larger quantity of heat will then be converted into work, and consequently the power developed by the engine will be increased." He gave these quotations from known authorities, in order to show that the views he had expressed had been present in other minds for some time past. It might perhaps be wondered why they had not been acted upon to a greater extent. The reason was that only recently had the urgent necessity for considering the question been recognised, since large engines had been built which had to be worked with generator, or some analogous similar gas, because coal-gas was too expensive. Mr. Dowson.

Mr. Graham Harris said it had been his good fortune for some years to have to consider the internally-fired engine of which the gas-engine was a typical example. In 1889, he gave a series of Cantor Lectures at the Society of Arts, in which he fully considered that class of engine; and he endeavoured to show that the prophecy made by Sir Frederick Bramwell, at the jubilee Mr. Harris.

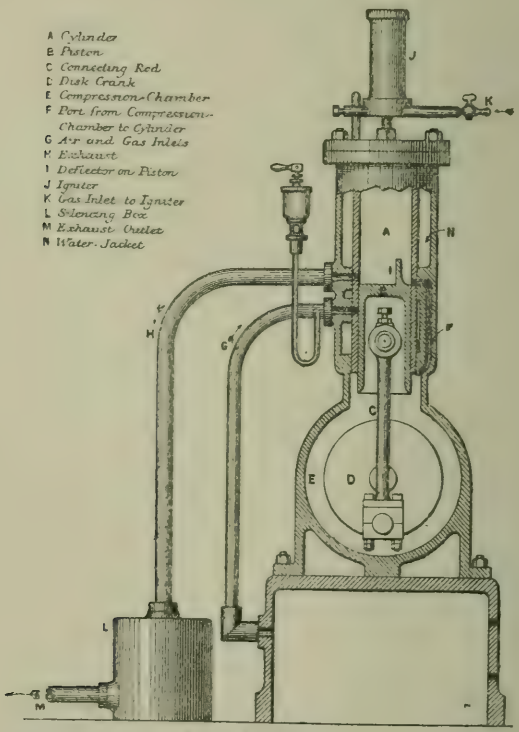
Mr. Harris. meeting of the British Association, in 1881, would, almost certainly, be unique among modern prophecies in that it would prove to be correct. Sir Frederick had said that at the jubilee of that meeting, in 1931, engineers would look at steam-engines of small size as articles of antiquarian interest, that they would be put in museums, being out of use altogether, and superseded by internally-fired engines. When the Paper was issued, Mr. Harris had read it with great interest. He had thought that the Author was a staunch advocate of the gas-engine, and that its cause was therefore in good hands. He had, however, been extremely disappointed, for the Author had adopted the course of advocating the cause of the gas-engine by making disparaging statements as to its rival the steam-engine—statements which were not as accurate as they should be, in view of the fact that they were to be published in the Proceedings of the Institution. To show to what straits the Author was driven in his endeavours to disparage the steam-engine, Mr. Harris would like to draw the attention of the members to the picture drawn in such graphically descriptive words, on pages 23 and 24 of the Paper, of the fearful results that must ensue from sending the large amount of high-pressure steam given off by the various high-pressure steam-engines at work in London, into its atmosphere. It was stated that this atmosphere was appreciably injured by the steam and by the products of combustion from the boilers generating the steam. He would suggest that these would have as much detrimental effect upon the atmosphere of this vast city as a man spitting into the river at Teddington Lock would have upon the cleanliness of the River Thames at Westminster Bridge. He was the more disappointed with the Paper, especially after reading its title, because he had been one of those who had contended that the gas-engine was the proper machine to drive the dynamo to produce electric lighting. It was not a perfect machine for that purpose yet, but would soon attain that position. The public and domestic lighting was in most towns in England in the hands of the great gas-companies who had spent large sums of money for the purpose of providing a satisfactory supply. If the electrical engineer could only persuade the gas companies that it was the proper thing for them to supply electric light, there was not much doubt that lighting by electricity would progress with much more rapid strides than it had hitherto done. The gas companies had the plant for the manufacture of the gas, and the pipes through which, in many cases, the electric light wires might be laid; and if they were to produce an inferior gas sufficiently good for heating and power purposes, such as the

Dowson gas, and used it for driving gas-engines to produce electric light, surely that would be to their advantage, and would lessen the evil effect upon them of the rivalry of the electric-lighting companies. That this was true was proved by what was being done at one place on the Continent, and was projected at three or four places in England. There were, however, two or three points in the Paper in which he quite concurred. He agreed that the present gas-engine, working with the Otto cycle, was not the most satisfactory engine to be used for electric-lighting purposes. At present no doubt the tendency of electric-lighting engineers was to carry the dynamo upon the same bed-plate as the engine, and to couple to the engine crank-shaft, and drive it at a fairly low speed. That made the best engineering job. In dealing with an alternating current at a high voltage, the dynamo coupled directly to a gas-engine using the Otto cycle formed an unsatisfactory arrangement; with only an impulse every two revolutions, irregularities in the voltage, and pulsations in the light, were sure to result, and the difficulties of working two or more such plants in parallel would be great. Further, the present form of gas-engine had another and greater fault when employed in the way suggested, which the Author had not pointed out—the fault of its mode of governing. The gas-engine which gave an impulse at every second revolution only did so at its full load. Its governing was achieved by cutting out explosions, so that one might well have a gas-engine running at half-load (a necessity that continually arose in a central lighting-station) and only get an explosion every 3 or 4 revolutions, thus emphasising the ordinary irregularity of the turning effort. What was wanted, therefore, was a gas-engine that would give at least as regular a turning movement as was obtained in a double-acting steam-engine—which would run at a fairly low speed—and might be easily coupled direct and carried on the same bed-plate as the dynamo. There was a gas-engine practically of that character, or one which bade fair to be able to do all that he had said, which had been lately developed by Mr. Day, and he had thought that it might interest the members to see a rough working model of it. He would first point out that, judging by the indicator diagram obtained from it, there was nothing abnormal in its working. The diagrams exhibited had been taken from an engine running at the office of his firm in Great George Street. The engine consisted, in its moving parts, of a piston, a connecting-rod, a crank-shaft, and nothing else; there was absolutely not a valve in it except the governor valve, which could hardly be called a part of the engine, as it

Mr. Harris.

Mr. Harris. could be done without. It was certainly a simple engine and one easy to make; and it had one advantage not possessed by other gas-engines, which was that it would run whichever way it was started, two or three sharp turns being given to the fly-wheel by hand in the direction in which it was desired the engine should revolve. This capability of running in either direction was, of course, no advantage for electric-lighting purposes, and he simply drew attention to it incidentally. It would be seen from *Fig. 1*,

Fig. 1.



"DAY" ENGINE.

which presented a sectional elevation of the engine, that it was of the vertical class, with an over-head power-cylinder A, below which the crank-shaft worked in a closed chamber E, in a manner somewhat similar to that adopted in the Willans engine. The movement of the piston B upwards closed the connection E between the compression-chamber E and the power-cylinder; a still further movement of the piston upwards caused a vacuum in that

chamber, and when the piston reached the top, it opened the gas- and-air-inlet, at which time there was a vacuum of about 2 lbs. in the chamber. The continued movement of the crank-shaft brought the piston downwards and closed the inlet, compressing the explosive charge of gas and air which had been drawn in to the crank-chamber, to a pressure of about 2 lbs. per square inch, sufficient to force it, when the connecting pipe F was opened by the continued movement of the piston, into the power-cylinder above. The incoming current of explosive mixture being directed upwards by the lip I on the piston, to the top of the cylinder, was thereby prevented from going out of the exhaust port. The continued movement of the piston closed the connecting-pipe F, and the exhaust-port H, and compressed the charge in the top of the cylinder. This charge was fired with an ordinary tube igniter, the explosion driving the piston downwards; and that cycle was repeated in each revolution. When he first saw the engine 8 months ago he feared that it would be impossible to run it at any speed. It seemed to him almost certain that back-explosions would occur, and that troubles would arise from this and other causes; but he had that day seen an engine developing 4 IHP. at 350 revolutions per minute with an absolute certainty of an explosion at every down stroke. Now, if two such engines were placed side by side, and the cranks set at opposite angles, the same equality of turning movement would be obtained as in an ordinary single-cylinder double-acting engine, and the crank-shaft of the engines might be coupled direct to the dynamo-spindle. If three such engines were put side by side with the cranks at equal angles, a turning movement as absolutely regular as that of a Willans engine would be obtained; and every electrical engineer would agree that the Willans 3-cylinder engine was a proper motor to couple direct to a dynamo.

Mr. Harris.

Mr. Henry Lea thought that, for driving mill-machinery, the advantage of the Dowson gas-plant did not seem very clear. But the case was very different when electric-lighting stations were considered. Figures had been published showing the cost of coal per unit of electricity sold by several electric-light companies. Taking, as an example, the company which produced and sold the largest amount of low-tension electricity in 1891, the cost of coal was 1·05*d.* per unit. With coal at 15*s.* per ton, this worked out to about 9¾ lbs. per electrical IHP., or, allowing 30 per cent. for loss in the generation and transmission of the electricity, the result was about 6¾ lbs. of coal per IHP. If 1 IHP. could be produced for a consumption of 1½ lb. of coal per hour, there would be

Mr. Lea.

Mr. Lea. left $5\frac{1}{4}$ lbs. of coal per HP. per hour, less the waste in the generating-machinery. But, inasmuch as it appeared that the Dowson gas-generator could be instantaneously damped down by simply turning off the supply of steam, and that the coal would go on smouldering for hours with very little loss, ready to be quickened up, and to produce the full volume of gas whenever the steam was turned on again, it seemed that the use of this kind of plant for the intermittent work of an electric-lighting station must result in a great decrease in the cost of fuel. No doubt the gas-engine must be coupled directly to the dynamo, and must be made to give more impulses per revolution; in addition to which it would be necessary to introduce a heavy fly-wheel. He had a great respect for the heavy fly-wheel; it was cheap and durable, and its steadying effect might be increased to almost any extent. Probably, if gas-engines had always been provided with fly-wheels of about 3 times the customary weight, there would have been far less trouble with belts and unsteadiness of currents from dynamos. The case of a 2-HP. Crossley engine had been cited, which was under the control of the governor, *i.e.*, not exerting its full power, and under those conditions, the consumption of gas per unit was 55·6 cubic feet per hour. A smaller pulley was then put upon the dynamo, and the trial was arranged so that when the engine was working at full power, it was turning out the required amount of electricity. The consumption of gas decreased to 51·4 cubic feet per unit per hour. The result was suggestive wherever a gas-engine was applied to work a steady load, such as that of charging secondary cells. The reason for it was that, as a rule, when a gas-engine made a miss on account of the governor having shut off the supply of gas, the first diagram that occurred after the miss never showed full power, but had a shape more like that in Fig. 14, Plate 2. The second diagram after the miss was a little better than the first; but there might be 3 or 4 diagrams, each increasing in size, before the full-power diagram was obtained. It was obvious that whenever the gas-valve was opened by the governor-movement, the engine took in a full charge of gas; and therefore every charge that produced a small diagram led to a waste of gas. On the other hand, when the engine had a full load and exploded every time, it invariably gave a full-power diagram. In the particular case alluded to, the speed was reduced from 200 revolutions per minute when the governors were acting, to 130 revolutions per minute, at which speed the engines could only just perform the work that was required.

Mr. William Foster alluded to three methods of manufacturing cheap fuel-gas, which had been proposed and to some extent practised. There was the system of producer-gas, that of water-gas, and that of so-called generator-gas. In order to obtain producer-gas, air was driven through heated coke or coal, preferably anthracite; and the resulting gases were mainly carbonic oxide and nitrogen. There could not theoretically be more than 40 per cent. of combustible carbonic oxide; and he believed that the amounts rarely reached more than 30 to 35 per cent. The next step was to reverse the process of passing the air in, by passing steam through the heated fuel—obtaining the so-called water-gas, containing 90 per cent. or more of combustible gases. The Author's method was a compromise between the two; and, like many compromises, it seemed to have a satisfactory result. He observed on the wall a diagram that was suggestive of some one having an interest in the much puffed and praised water-gas. He did not wish to be uncharitable; but the only successes which he had heard of in connection with water-gas, were, he thought, to be traced largely to Stock Exchange operations. Water-gas no doubt had its uses, but its preparation involved blowing up so many minutes with air, and making a considerable quantity of producer gas, then turning on steam for some minutes; when, barring accidents, the result was all right. It meant, therefore, that unless there was a rise for the producer-gas made, there must be a considerable waste of the fuel used for getting the water-gas; and that had been one of the chief difficulties in carrying on the double process, when one of the products only had been aimed at, viz., water-gas. It was, of course, a poor device, that of mixing producer-gas and water-gas after manufacture. The happy mean had been taken by the Author, and, as the one process was a heat-producing (exothermic) action, and the other a heat-using (endo-thermic) action, by balancing the air and steam in the way he did, a condition of change and maintenance of temperature was arrived at, attended with production of gas which, according to several observers, contained something like 45 per cent. of combustible material. That was clearly a great advance on the producer-gas of the late Sir William Siemens, which contained only 30 or 35 per cent. of combustible material, and was therefore useless for many purposes, unless the principle of recuperation could be applied, advantage being taken of the waste heat. The obtaining of that 45 per cent. of combustible gas was a matter to which the Author had given much attention some years ago, and from the fact that he had not since increased the combustible proportion, it Mr. Foster.

Mr. Foster. would seem that he had arrived at a method of manufacture based on some well-known law. There was a certain portion of carbonic-acid gas always present, but the amount of the combustible was, judging from experiments made by others, maintained fairly constant. The temperature at which the change occurred was a matter that had been debated severely in the Law Courts in Edinburgh two years ago, in connection with the question of chemical change occurring in paraffin-distillation. He had something to say on that matter, and thought there was no great difference of opinion on the main issue—that the temperature of the heated material was something like 800° C. What the temperature of the effluent gases might be he had no means of stating; probably it was not less than 400° C. He would enquire (and he was rather taking the cue from the Author) whether it was not possible, in any attempt on the part of those who wished to enhance the combustible part of the fuel made by the double process of passing in steam and air, to use the surplus heat carried away by the generator-gases out of the generator? It seemed to him that if there was only one-half the temperature of the incandescent coke or coal, a considerable balance must be available for contributing to the double exo- and endo-thermic action, so as to increase the amount of steam which could be decomposed in the generator; any communication of heat in that way should be attended not only with an addition to the combustible material, but with decrease of the nitrogen. It seemed a small thing to increase the percentage of combustible material by 10 per cent.; but what did it lead to? With 33 or 35 per cent. of carbonic oxide, and the remainder nitrogen, they had a ratio of 1 to 2. With the Author's method, the combustible material being 48 per cent., and the rest nitrogen and carbonic acid, there was a ratio of about 1 to 1. That showed the advantage of any such application. He thought the Author had done wisely in appealing to business men to proceed on the basis of the unit of solid fuel employed. There was one matter on which he would suggest a possibility of improvement, namely, the work of the gas-engine. He had taken some trouble to look into the matter, but had found that none of the exhaustive reports that had been published, such as the Report of the Society of Arts on the trials of motors for electric-lighting purposes, said a word about the effluent gases from the gas-engine cylinder. The Law Courts' records might give some information respecting it. Fifteen months ago he had been called upon to make some experiments on the combustion of coal-gas and air in fixed quantities in a

close vessel. The conditions were not the same as those which obtained in a gas-cylinder; but the results, though suggestive, were very unsatisfactory from his client's point of view. He dared not say more. The combustion was not anything like what he should have desired to see it. He was not certain that the gas-engine was doing the work it ought to do in the matter of combustion. He was led to that conclusion partly from what he had observed, and partly from the evidence afforded by the smell where gas-engines were placed in cellars without any provision being made for getting rid of the products of combustion. It was an important question to ascertain how far the work obtained from the fuel was complete. He had no confidence in the combustion effected with large quantities of combustion-products added to modify the explosion. It might modify the explosion, but was that the best way of getting out all the working capabilities of the fuel introduced, and was the combustion anything like complete? Many would be familiar with the *ex cathedra* opinion of a learned judge, whose name was revered and respected by the members of the Institution, as to the veracity of expert witnesses. He would not attempt to confirm that opinion, but there was enough in the Paper to support it. In Appendix F, a chemist, whom he did not know, had given a number of observations, and had attempted to give the very information which Mr. Foster had long been desiring to have with regard to the products of combustion from the gas-cylinder. But gas containing 60 per cent. nitrogen and a quarter of its volume oxygen, besides the combustion-products which had their oxygen from the air, presented a puzzle which he was perfectly unable to solve. The point which he wanted to dwell upon was that this chemist found no less than 15·69 per cent. of carbonic oxide in the effluent products, and was clearly inexperienced in those matters. It was quite impossible to discuss the nature of effluent gases on that basis. Mr. Foster had not forgotten the severe homily which Dr. Tidy had preached in that room. It was one of the recollections of his life. He was rash enough 10 years ago, to suggest the use of water-gas as a means of enhancing the value of the residuals of coal, and, bearing in mind Dr. Tidy's powerful remarks on the iniquity of suggesting the use of carbonic oxide as a means of lighting houses (which he never did—he had only suggested what the Author had done)—he should be sorry to offer any modifying opinions on the noxious character of that gas. It behoved every engineer who was interested in advancing fuel-gas, to take precautions to secure proper exit of the products of combus-

Mr. Foster.

Mr. Foster. tion. He held that those products were amongst the most offensive matters in connection with the gas-engine, and, in the interest of all concerned, every means should be taken to get rid of them.

General Webber. General WEBBER desired to confine his remarks to the question as it presented itself to electric-lighting engineers in designing stations. Many engineers, in designing generating-stations, had for some time past turned their attention to the utilization of gas-power. The obstacles which they had encountered had been more of a financial character than from any inherent difficulty in the work. Even five years ago, a station in London, now fitted up with steam-plant, was designed for a gas-engine plant. In 1890 he had to specify for the plant for an electric-light generating-station with an output of about 660 HP. The specification was so drawn that contractors could tender power derived from steam with high- or low-speed engines, or power derived from gas as fuel. The steam-power had the advantage of means for condensing with about 350 I.HP. or rather more than one-half of the output of the station. Trials of the plant under that specification were to be directed towards ensuring a guaranteed economy of fuel; and, following the Admiralty system, so as to prevent any speculative tenders being sent in, the prices of the tenders were to be compared by making an addition to, or a deduction from, each, according to the guaranteed economy—the basis of comparison being that a saving in fuel equivalent in cost to $\frac{1}{10}$ lb. of coal per hour in the consumption necessary to produce 1 electrical HP. should have a capitalization value of 10*s*. The check on speculative tendering was further prevented by the request to tender being confined to three firms, which he would designate by the letters A, B, and C. Firm A proposed tubular boilers and low-speed steam-engines, belt-driving; B, Lancashire boilers and high-speed engines, direct coupling; C, gas-generation and gas-engines. The tenders included the dynamos, with all the equipment of the station except the electrical fittings beyond the terminals of the dynamos. The sum included the installation, but no building-work. In that case, owing to the circumstances of distribution, the units of power were small. The approximate amounts of the three tenders, crediting the gas-plant with £200 for a chimney-shaft that was saved, came out nearly as follows:—A, £27 per electrical HP.; B, £28; C, £33; and the guaranteed coal-consumption with full load under the conditions described, was in the first case, 3 lbs. per electrical HP.; in the second case, 3·1 lbs.; and in the third case, 2 lbs. The saving in fuel between C and A, with the full load running 1,200 hours out of a whole year,

was 350 tons. The units of that particular plant being small, either with steam- or gas-engines, the consumption of steam during the remaining 7,560 hours of the year would not compare unfavourably with that of gas; but the difference of cost between maintaining the boilers in a condition such as that referred to by the Author for getting up steam, and in the generators for making gas, showed in any case a considerable saving of fuel. In 1890, at the time when that comparison by tenders was made, the old prices of gas-engines were still maintained. There was no doubt that if the present prices had ruled then, the tender of C would have been reduced by as much as 42 per cent., so far as concerned the actual cost of the gas-engines that were tendered for. That amount would have equalled £3 per electrical HP., reducing the £33 to £30, thus making the comparison wear a very different aspect. In capital expenditure, the saving would have been £2,000, which would have brought the totals of the three tenders to nearly the same figure. He thought it a fairly accurate comparison in the sense that it was the outcome of the independent tenders of three firms, each tendering under different conditions, but upon the same data; showing that one of the circumstances which had operated disadvantageously to the industry had been due, up to 1892, to the extremely high price of gas-engines, by which the cost of a combination of the gas-engine and generator had always been deterrent, as compared with the cost of an engine and boiler. General Webber.

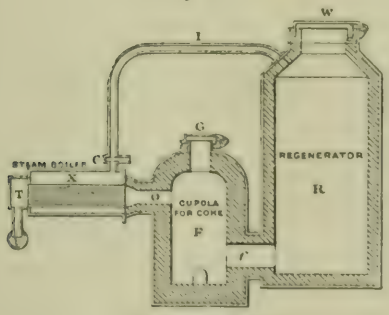
Mr. E. A. Cowper said that the subject of obtaining useful gas from the decomposition of water, and the production of carbonic oxide, had occupied the attention of engineers for so long a period, that it was difficult to say when the advantageous use of such gas commenced. He believed that Brown in his "gas vacuum-engine," as it was called, used ordinary carburetted hydrogen; but his machine was not successful, and was only used for lifting water. In 1851 Mr. Cowper had been called in by Mr. De Castro, to examine some water-gas apparatus invented by Mr. Alfred White in 1847. In that apparatus, the carbon was confined in a retort, and kept hot by a fire outside; the steam being introduced inside, and passing through the carbon, became decomposed, thus forming carbonic oxide and hydrogen; but, as much heat was expended in converting the solid carbon into a gaseous state, the operation could not be conducted either quickly or economically, as the heat passed slowly through the walls of the retort. Under these circumstances, it was almost impossible to keep the centre of the mass of coke in the retort at the same temperature as Mr. Cowper

Mr. Cowper. the outside. The resulting gases were to be enriched afterwards by oil or hydrocarbons for illuminating purposes. The scheme, however, came to a standstill. He felt peculiar interest in the Author's successful application of good gas for driving gas-engines, because, in 1857, he had proposed and published two arrangements, either of which was far more economical than previous plans for making water-gas. In both of those plans the apparatus was to be worked intermittently, as in all water-gas plant—the mass of fuel being heated up, by admitting some atmospheric air for combustion, thus forming "producer-gas," and steam being afterwards blown through the incandescent mass to produce "water-gas." The steam was to be highly superheated before being introduced among the incandescent fuel, so as not to chill it, but to carry in as much heat as possible, for the production of hydrogen and carbonic oxide, without any nitrogen, and with as little carbonic acid as possible. When air was admitted to raise the temperature of coke, rendering it completely incandescent, a considerable portion of the latter was burned, and, of course, went off as "producer-gas," mixed with all the nitrogen of the air which entered. The high temperature of the steam was to be obtained by burning some of the "producer-gas," to heat a good regenerative fire-brick stove, such as a "Cowper stove"; so that a temperature of 1,500° F. to 1,800° F. could be readily obtained in the steam so treated. The water-gas produced was to be passed through the tubes of a steam-boiler, in order to save heat and to furnish steam if the gas was not to be used for illuminating purposes. If the gas was to be so used, it had to be mixed with hydrocarbons. The apparatus was illustrated in *Fig. 2.* F was a fireplace or cupola partially filled with ignited coke; *f*, a passage communicating with a regenerator R; W and G valves; O, an outlet leading from the cupola F to a steam-boiler X; and T was an air-tight box leading to the hydraulic main U. I was a steam-pipe from the boiler X to the top of the regenerator R, furnished with a cock C. The valves W and G were opened, and, whilst the coke in the cupola F was becoming thoroughly heated up, the products of combustion and "producer-gas" passed up through the regenerator R, and heated it; then the valves were shut, and the steam-cock C was opened, when steam passed down the regenerator R and became highly heated; it then passed up through the hot coke in F, becoming decomposed into "water-gas," which passed through the boiler X and heated it, and thence into the hydraulic main U. He rejoiced to find from the results obtained by the Author, that it was now possible

to work improved gas-engines at so much less cost than could be done with ordinary town-gas. In many of the old gas-engines, the amount of cooling of the cylinder was considerable, and the arrangements of the chamber in which the combustion took place were such as seemed to be intended to rob the gas of as much heat as possible; whereas, within practicable working limits, the gas should be kept as hot as possible, so as to get the utmost work out of it at the time of explosion. The cylinder could always be kept cool by a water-jacket, and must be situated far enough away from the explosion-chamber. That was a matter of mechanical arrangement. The application of gas-engines so worked to the peculiar duty required for electric-lighting was admirable, as there was but little loss in stopping and starting, compared with the loss of fuel with steam-boilers, even when constructed to hold

Mr. Cowper.

Fig. 2.



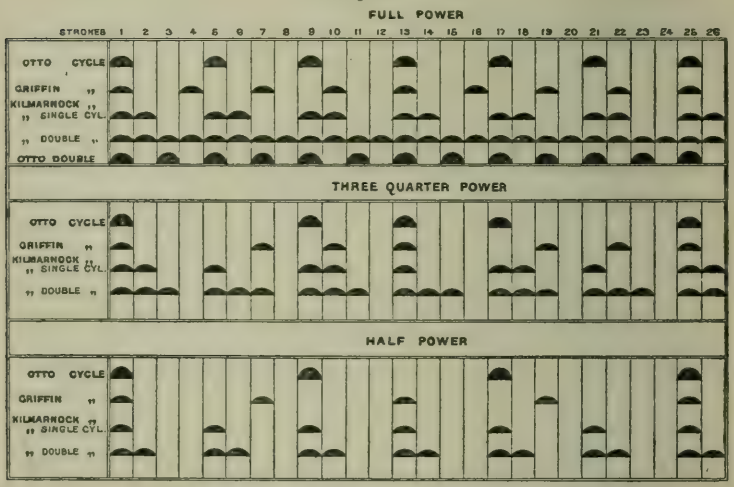
"COWPER" STOVE.

but little water; and the comparison was still more favourable with ordinary boilers containing much water and working continuously throughout the day. He also looked forward to greater improvements in gas-engines in a certain direction not hitherto attempted. He understood that Mr. Woodall, in association with American engineers, was engaged in introducing carburetted "water-gas" on this plan into gas-works in Europe, and he hoped that a description of it would be given. The main principle seemed to be, that after "water-gas" had been produced and hydrocarbons had been distilled in the form of vapour, they passed through a very hot chamber something like an ordinary regenerative stove, so as to thoroughly fix the vapours in the form of gas; they were then stable, and would not condense in any cold place through which the main happened to pass. If that could be done in a thorough manner, it would be a great advantage,

Mr. Cowper. because the mineral oil employed in the process could be imported at $2\frac{1}{2}d.$ to $3d.$ per gallon, and that compound of water-gas would form an extremely cheap illuminating gas of about 20 candle-power.

Mr. Hartley. Mr. J. W. HARTLEY said he understood that one of the principal features of a gas-engine using Dowson gas for electric lighting was steadiness of running, and to illustrate his remarks, he had prepared a diagram, *Fig. 3.* The upper line represented the explosions of an Otto cycle engine running at full power. There was one explosion to three idle strokes. Therefore, when an Otto engine was running at full power, there was one impulse to three misses, so

Fig. 3.


FULL POWER
STROKES 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26
OTTO CYCLE
GRIFFIN ,,
KILMARNOCK ,, ,, SINGLE CYL.
,, DOUBLE ,,
OTTO DOUBLE
THREE QUARTER POWER
OTTO CYCLE
GRIFFIN ,,
KILMARNOCK ,, ,, SINGLE CYL.
,, DOUBLE ,,
HALF POWER
OTTO CYCLE
GRIFFIN ,,
KILMARNOCK ,, ,, SINGLE CYL.
,, DOUBLE ,,

COMPARATIVE CYCLES OF GAS-ENGINES.

that the impulses actually operated only during one-fourth of the whole travel of the piston. In the Griffin engine, which used a cycle with which many of the members were no doubt conversant, there was one impulse to two misses. Therefore, the Griffin double-acting engine, running at full power, was obviously more regular than that of the single-acting Otto cycle at full power. In the double-acting Otto cycle, such as that made by Messrs. Dick, Kerr & Co., of Kilmarnock, when running at full power, there occurred two impulses, one immediately following the other, then two misses, and so on; one-half the strokes of the engine being impulses, and one-half misses, as compared with one impulse to three misses of the single-acting Otto, and one to two of the Griffin cycle. The Griffin

cycle showed better results than the Otto cycle in respect of uniformity, but was not equal to the double-acting engine to which he had referred. It would be seen that the explosions in that engine at half-power were the same in number as in the Otto at full-power. A coupled double-acting Otto cycle-engine was therefore the best form of electric-lighting engine of any of the cycles referred to. From the diagram, it would be seen that the explosions were continuous, exactly the same as in a single-cylinder steam-engine. When working at 180 revolutions per minute, there occurred 360 impulses in a minute, at equal intervals of time. That would be obviously sufficient, under ordinary conditions, for absolute steadiness of running for electric-lighting purposes. In reducing the power, the charges were reduced in strength, so that perfect steadiness could be insured from full-power down to the power required to turn the engine alone; and at all powers, there was a continuous number of steady and continuous impulses. In order, further, to secure steadiness of revolution, the initial pressure of the explosion in the cylinder was purposely kept down within reasonable limits, and hence the severe shocks which had resulted in broken crank-shafts in large-sized coupled gas-engines were avoided. Referring to the diagrams, Wandsworth, Figs. 8 and 9, Plate 2, it appeared that there was in the cylinder 200 lbs. pressure and 80 lbs. compression per square inch, which must have administered a blow something like that of a steam-hammer on the dead-centre of the engine. That did not appear to be a satisfactory way of transferring power to a rotary machine. Assuming the terminal pressure to be 45 lbs. or 50 lbs. per square inch, the difference between the terminal and the initial pressures would be about 230 lbs. Any engineer, whether interested in gas- or steam-engines, would agree that this was an enormous difference of pressure to be exerted in one cylinder with safety and economy. He might point out, as a somewhat extraordinary fact, that continental manufacturers seemed to have recognised this; and, referring to the diagrams marked "Rouen," Fig. 11, Plate 2, it would be seen that there were 79 lbs. per square inch of compression. Unfortunately, the initial pressure was not given; but it might be assumed, from the proportions of the diagram, that it would not exceed an additional 79 lbs. per square inch. From the unusual appearance of the diagram, it might be assumed that the piston of the indicator had been sticking; the upper lines could not have been correct. The same remark applied to the diagram, Fig. 14. If the piston of the indicator had been forced up to the stop, the upper lines would

Mr. Hartley.

Mr. Hartley. have been parallel. The central pressure was shown much lower than that of any of the other cards exhibited. The results stated in connection with this engine showed that the present practice was not in the right direction; and that it was bad not only in principle, but also as regarded economy and safety, to permit so wide a range of pressure as 230 lbs. in one cylinder. Neither was it possible to obtain steadiness of running under such conditions. That afforded matter for reflection on the part of makers of gas-engines. It appeared strange that this apparently vital point had not received the attention it deserved, as cards of the Rouen engine were, he believed, published in *Engineering* about two years ago, but no one in this country seemed to have taken any notice of them. The two things in combination—the reduction of the high initial pressure that was now used, and the employment of a cycle similar to the one just described, combined with properly graded charges—gave the best result that could be obtained in point of steadiness in the gas-engine, and consequent suitability for electric-lighting purposes.

Professor Kennedy. Professor ALEX. B. W. KENNEDY said that, in speaking of gas-power for electric lighting, the Author was thinking of central-stations and not of domestic lighting. He had looked forward to the Paper with great interest when he saw its title announced, but he was to a certain extent disappointed. For this he could not blame the Author, because it appeared that so little had yet been actually done in the matter, that it was only possible to say what ought to be done. That, however, was a thing which time would doubtless remedy. Reference had been made by the Author to the probable influence of the use of gas-engines, either with Dowson-gas or town-gas, on economy in central lighting-stations, mainly in connection with load-factor. In that, Professor Kennedy would follow him, because it might be well to clear up some of the matters referred to, and to make the figures as exact as possible. Of course it was known what were the best results that could be obtained with either steam or gas, and that a gas- or steam-engine could give its best results only when working continuously for some time at full power. In the case of boilers, the best results that could be obtained were also known, and they could only be obtained from continuous work, but not at full power—perhaps at about three-quarter load. Further, in engines either using gas or steam, the steam or gas used per I.HP.-hour increased rapidly as the power diminished, while the consumption per electrical HP.-hour increased very fast indeed as the power diminished. For instance, at half-output, the consumption of gas

or steam per useful HP.-hour was about 40 per cent. more than at full output. Of course it was mainly here that the loss in the engines, due to load-factor, came in. With the boiler it was different. In the first place, if the working was only steady, the boiler would do its best at half- to three-quarter power, and even from one-quarter power onwards it did not work very wastefully. The loss occurred when the boiler was standing still; it might be called stand-by loss, rather than loss due to low load-factor. He had ascertained it frequently by measuring separately the coal used in the boilers of a station while the stop-valves were open, and while they were shut down. The coal used in boilers of which the stop-valves were closed was obviously waste coal. Taking the boilers first—from experiments made in this way, he had found it was possible to reduce the standing loss to 10 per cent.; that was, the consumption of fuel in boilers which were not making steam was about 10 per cent. of the whole consumption in all the boilers. That was in London, where there might be a fog at any time, in consequence of which it was most necessary to keep stand-by. As to the engines and the effect of load-factor of engines, on which the Author had properly laid a good deal of stress, it was commonly said, and said with some authority in the Paper, that nothing was easier than to keep the engines at full load, if only the units were small enough, they were handled skilfully, the batteries were charged in the daytime, and so on. He had been scoffed at for using too small units, rather than too large ones; and he knew that the gentlemen who were in charge of his stations were wide-awake and capable engineers, and thoroughly alive to the importance of loading their plant; and yet, even at the present time of the year, they found it difficult to get a load-factor of more than 65 or 70 per cent. The ratio which he called the load-factor was obtained in this way: he took the number of engine-hours per week; he multiplied the hours worked by each engine by its full-load output, and added the products together. He thus found how much the station would have done with the same engines working the same number of hours, if they had been running all the time at full load. He compared this with the actual output during the week, and the result was about 65 per cent. He hoped that nobody who was shocked by this would compare it with the figures which they obtained on a single day, or over 8 hours, or anything of that kind. The comparison could only be fairly made by figures taken from week's end to week's end, including all the nights and all the Saturdays and Sundays and so forth. He could to some extent analyse the figures, and show the effect in some cases of

Professor Kennedy.

Professor Kennedy.

the losses, and the points in which they could be partly made up by the use of gas instead of steam. He would in this connection give actual and not merely imaginary or illustrative figures. He used non-condensing engines which always gave a test result of 24 lbs. of steam per electrical HP. at the terminals, which was equivalent to 32 lbs. of steam per unit. He used boilers which gave 11 lbs. of steam per lb. of coal, under standard conditions (that was about 9½ lbs. of steam actually sent to the engines) also on test. He ought therefore to use about 3·4 lbs. of coal per electrical unit delivered; instead of which the last three or four weeks, he had obtained at two stations a figure which averaged 5·3 lbs. That was much better than the average of the year, but he gave the figures as they occurred. He accounted for the difference, which was 1·9 lb. per unit., in this way. First of all, 10 per cent. stand-by boiler loss, 0·53 lb. Then he knew from experiment that, working at 65 per cent. load-factor on the engines, he lost about 25 per cent.—that was, the steam per electrical HP.-hour would be increased 25 per cent.—so that there was 25 per cent. of engine loss on 3·4 lbs., or 0·85 lb.; and, adding that to the 0·53, gave 1·38 lb., leaving 0·52 lb. still to be accounted for by the low-load factor of the boilers, and by all the miscellaneous losses in the station. How would the use of gas-generators and gas-engines help him in that matter? The loss on the boilers, 10 per cent., of course would be entirely saved by the use of town-gas, which he supposed was meant in the remarks on p. 10 of the Paper. He did not now discuss town-gas, because it was hardly proposed by the Author that it should be used for central-stations. He wished to say, however, that he thought there were certain circumstances under which its use, in spite of the cost, might be preferable to that of either steam or generator-gas. How far the 10 per cent. could be saved by the use of generators, he could not ascertain from the Paper, because the real effect of load-factor on generators had not been stated. Some figures given by the Author referred to experiments at Chelsea, but he did not think they could be fairly compared with long-duration figures such as those taken from one week's end to another. They were not figures from which load-factor conclusions could very well be drawn, although, no doubt, they were right as far as they went. A settlement of the question might be arrived at by an experiment over a week, or a year, giving the ratio of the total fuel used per I.HP. to the fuel used on a proper trial run. As to the saving by improvement in engine load-factor, which in his case was the most important cause of loss, of course a gas-

engine would not help them at all. A gas-engine had exactly the same drawbacks in that respect as a steam-engine. Five 200-HP. gas-engines, with the same engineer to use them, would give about the same proportional loss for the same load as five 200-HP. steam-engines. Therefore it would not affect that part of the loss. It might affect the final difference, because the casual losses in gas-plant might be less than steam-plant; but, on the other hand, they might be more. He thought the Author had perhaps overlooked this aspect of the engine load-factor question, because the mere use of a gas-engine instead of a steam-engine could not improve matters. As a matter of fact, the consumption of gas per electrical HP.-hour increased, according to his experiments, as the output of the gas-engine fell off, in practically the same ratio that the consumption of steam per electrical HP.-hour in a Willans engine increased as the electrical HP. diminished. As regarded the figures given in the Paper, they certainly reflected the highest possible credit on the Author's skill in working the producer-gas process, and also on the gas-engine makers for the great improvements made in gas-engines within the last few years; but he did not think those figures bore unimportantly on the special subject of the Paper—the applicability of engines worked by generator-gas to the actual requirements of large central stations. The trial figures which were given were interesting, and he did not for a moment doubt their accuracy. The figures of economy obtained in trials must, however, be largely increased in order to adapt them to the trying conditions of such central stations as he had mentioned. The economic figures got from mills and other such places must also, to a large extent, be increased. In central-stations, the useful horse-power was known; in a mill it was not so. Even the true average indicated horse-power was not known with any pretence to accuracy; and so the results per I.HP. per hour from mills and factories had to be received with caution. Here he would point out that the Author had cited only one fair-sized central-station, that of Dessau. Town-gas was used there, not Dowson gas; but the figures would none the less have been valuable. He could not make out clearly from the Paper whether the consumption given, 39 cubic feet per kilowatt, was really a figure obtained by trial, or was the result of comparing the whole output in units in a month with the whole gas used in cubic feet during the same period. If the Author would mention that in his reply, he would add a very important piece of information. There was also a little electrical plant using Dowson gas at

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Schwabing. Was it not possible to get something in the way of results beyond the mere full-power run? It had been running for 3 years, and if the actual number of lbs. of coke and the quality of the coke used per unit for a long period were known besides the figure which was given,—which was a mere trial-figure,—it would constitute valuable information. Besides the questions to which the Author had mainly confined himself, there remained certain points as to the gas-engines themselves. They were apparently healthy children; but they grew slowly. It was long since big gas-engines had been promised, and he gathered that they were now coming soon, but they were a long time in coming. It was difficult for an engineer to make a large step upon faith in machines that did not exist—especially as it might be gathered from the Paper that it was not quite settled even what was the best cycle of operations to use. There were so many mechanical questions affecting large gas-engines for central-stations which did not affect the small ones, that it behoved them, in spite of everything, to move cautiously about the matter. He did not entertain any doubt that the Dowson plant working at full load would do more for a pound of coal than a first-class steam-plant at full load. From the Author's estimate, he gathered that it would also cost a great deal more—remembering that the dynamos would be very expensive if driven direct, because of the speed he mentioned. But apart from this, some more information was really required as to the real load-factor effect in generators; the loss in generators over 1 month or 12 months corresponding with the loss in boilers which he had mentioned, and which he thought was sometimes greatly exaggerated in the minds of people who had not actually measured it. If such figures could be obtained, he hoped that the Author would state them in reply. He also wished to know if possible something about the maintenance of gas-producers. The worst of a boiler was known and accepted. More information was required about the up-keep of gas-producers used in the extraordinarily intermittent fashion in which they would have to be used in central-lighting stations. He was sure that other speakers would not seriously compare a full-power trial result of gas-plant with average working results of steam-plant. He hoped that nothing he had said would be thought hostile to the use of gas-plant. Certainly nothing was further from his intention,—he was only trying to learn more about it. No one recognized more clearly than he did, the importance of reducing transformations of energy to the smallest possible number; so that he would wel-

come even the abolition of steam between the fuel and the engine, if it would do any good. Still, it was of great importance, in thinking of such a step, that the points aimed at should be seen clearly. He would only add one other word in reference to a remark of Mr. William Foster, who had rather upbraided engineers because they had never considered the question of perfect combustion in a gas-engine, and had not collected the products of combustion. It was only fair to himself to mention that more than 10 years ago he had raised that very point,[1] and since then he had repeatedly tried to collect the gases from gas-engines, with a view to analyse them. The collection of such samples was a difficult matter, and he had hitherto been baulked in his attempts in that direction, but he hoped that Mr. Foster would be more successful. In the Report on the Society of Arts Motor Trials (pp. 14 and 24), he had also dealt with the matter critically, and shown that there was reason for supposing the combustion to be very imperfect in some cases. Professor Kennedy.

Mr. Henry Davey observed that the Author had touched upon a subject which was interesting and valuable, not only to electrical engineers, but to all engineers using steam-plant, namely, the stand-by losses of steam-boilers. He did not know whether there were any published data on the subject, but if Professor Kennedy would kindly reduce the stand-by loss to lbs. of coal of known evaporative power per square foot of fire-grate surface, it would be extremely valuable. Mr. Davey.

Mr. Gisbert Kapp did not look to the gas-engine as a means, at any rate at present, for driving large central-stations—a work which could be done well with steam-engines—but he looked to it as a means of supplying small towns with electric current. In small towns the difficulty was to make the station pay. Taking for example a small provincial town which would perhaps require 5,000 8-candle-power lamps wired, the income from the sale of current would be about £2,500, and the cost of working was large in comparison with the income. The reasons why, with an installation employing steam-power, the cost of working on a small scale was comparatively high were manifold, but he might mention a few of them. In the first place, there was the larger site to accommodate boilers and coal stores. Then the choice of site was more restricted, and it was generally found impossible to place the station at the centre of the district to be lighted. This increased the cost of distributing-plant, and augmented the annual Mr. Kapp.

[1] Minutes of Proceedings Inst. C.E., vol. lxix. pp. 303, 304.

Mr. Kapp. charge in respect of interest on the capital outlay, which had to be included in the working expenses. The most important item was, however, the question of labour. With a large steam-power station, the wages of a few extra men required during the hours of minimum load formed a small matter; but with a steam-power station of 200 HP. or 300 HP. capacity, these wages became proportionately important. Most of the difficulties he had mentioned could, to some extent, be overcome by the use of gas- instead of steam-power, and it would be interesting to have the figures of the actual cost of producing electric energy for public supply in gas-power stations. Although he was not acquainted with any town except Dessau where gas was used for this purpose, he had designed, three years ago, and had since had under his care, an electric-light installation, which, although not so large as would be required for a central-station in a small town, was of respectable size. The power would suffice for 1,500 8-candle-power lamps wired in a town. It was, moreover, an installation which had been cited, he was sorry to say incorrectly, by the Author. He referred to the installation which had been at work since 1890 at Messrs. Tussaud's exhibition. The Author had given the consumption of gas per kilowatt-hour or per unit output as 50 cubic feet. He should be sorry to be responsible for the design of an installation where so much gas was burnt per kilowatt-hour. As a matter of fact, the consumption, taking the average figures of 18 days, was in winter 33·4 cubic feet per kilowatt-hour or unit, and in the summer, when the load was lighter, 36 cubic feet. So that tallied very well with the Dessau experience. He might mention that he had found the installation of an electric-meter by the side of the gas-meter of great economic advantage. The plant was in charge of a very competent man, who kept accurate records of the readings of both meters; and if there occurred anything which tended to reduce the efficiency of the plant, it was immediately detected on inspecting the meter-book. The interesting part of the installation was the actual cost, and by the courtesy of the directors of the company he had been permitted to extract from the books the running expenses. Allowing for everything chargeable to such an installation, such as interest on capital, maintenance of machinery, and renewal of battery-cells, the work done in connection with the lighting—not only attending the engines but putting up additional lights, of which 50 were added every year—and everything of that kind, taking the gas bill, and in fact the out-of-pocket expenses as they stood, the total amount for the supply of 72,224 units during 1892

was £1,196 2*s.* 6*d.*, which worked out at a fraction under 4*d.* per unit. That included the renewal of the lamps and every other expense. Omitting the cost of putting up additional lamps and the renewal of lamps, and counting only such expenses as were fairly chargeable under the head of generating expenses, the cost for the 74,224 units actually sent into the lamps during the year had amounted to £911 8*s.* 9*d.*—so that the unit produced on the premises actually cost 3·03*d.*, as compared with 7½*d.* which the supply-company would charge. In comparing these figures it should, however, be remembered that the load-factor at Tussaud's was higher than at central-stations; and that the supply-company had to charge, not only for producing the energy, but also for delivering it at the customer's door; and the latter charge, commonly called "cost of distribution," was absent in a private installation. If the supply-company's current had been taken, the total cost of lighting, including interest on capital outlay in wiring and fittings, renewal of lamps, labour, and fitting up additional lamps, would have been £2,500 per annum. Supposing the whole place had been lighted by gas, not using electricity, but burning a sufficient amount of gas to produce the same light in burners that would produce 3 candle-power per cubic foot, it would have cost £1,370 per annum; so that there was an actual advantage gained by using the electric light over lighting by gas direct. Mr. Kapp.

Mr. Dugald Clerk remarked that the Author had pointed to the irregularity of impulse as one of the weaknesses of the present prevailing cycle used in gas-engines. That irregularity was one of the inherent defects of the Otto cycle. The cycle was admirably adapted for gas-engines of small and moderate powers, say about 40 I.HP., but for large powers, from 100 to 1,000 I.HP., the difficulties attached to it became greater; though, to some extent, Messrs. Dick, Kerr and Co.'s double-acting Otto-cycle engines had overcome them. He could not regard the Otto cycle as the final solution of the difficulty, as he considered that an impulse every revolution, and even two impulses per revolution were obtainable by other cycles, without the two-to-one action or gear. It appeared that the Author considered an increased consumption of gas to be the characteristic of all impulse-every-revolution engines having a separate pump. That, however, was not the fact. Such engines could be made to give quite as economic results at full, or nearly full, power as Otto cycle-engines. The failure of impulse-every-revolution engines to give economy equal to that of Otto-engines had been principally with light loads, not with full loads. Where there were two cylinders to drive instead of one Mr. Clerk.

Mr. Clerk. a little more load must necessarily come upon the engine in running a light load, than when it was fully loaded. Consequently, most of the impulse-every-revolution engines having two cylinders, used a little more gas in light loads than the Otto-engines did; but so far as the consumption at full load was concerned, their results had been equal. So early as 1881 he had accomplished 21 cubic feet per I.HP. He had since, in 1887, built engines which consumed, for so small an engine as one of 9 brake HP., 22½ feet to 23 feet—impulse-every-revolution engines, with separate pumps. Hitherto the Otto cycle had carried the day, simply because of the greater ease in carrying it into effect. There were difficulties peculiar to impulse-every-revolution engines; but, notwithstanding those difficulties, he had no doubt that, for large engines, a way would be found to use an impulse every revolution, and two impulses per revolution, and obtain greater economy than with the Otto cycle. He granted that, for small-power engines, the Otto cycle was the most suitable yet discovered, but for large-power engines it would undoubtedly fail, and would be looked upon as quite as barbarous compared with the future gas-engine, as the old Newcomen engine was compared with the double-acting steam-engine of the present day. There were many points of difficulty in building large engines, for either the Otto or any other cycle. The principal point was that, in large engines, the cooling-surface was small in proportion to the volume of the gases burned in the cylinder. The consequence was, that the products of combustion retained heat to a much greater extent than was the case in small engines; and the high temperature—over 1,000° C.—was liable to ignite the incoming gases. The result was, that large-power gas-engines at full load were rather more liable to back ignitions and pre-ignitions than those of smaller size. In 1882 he had divided gas-engines into three classes:—1. non-compression-engines; 2. compression-engines, in which the pressures of the gases remained constant, whilst the volume changed under the heating effect of the flame; 3. engines in which the volume of mixture remained constant and the pressure rose.[1] The third type was the engine which had made its way so largely into public use. He entertained the belief that the second was likely to be the type of engine for large powers. A good deal had been done towards perfecting the latter machine; and, although as yet no engine had reached the market using the second type cycle, he did not doubt, now that a demand for large gas-engines was arising, that in a short time it would

[1] Minutes of Proceedings Inst. C.E., vol. lxix. p. 220.

be adopted for large powers. He had been conducting experiments on that cycle for six or seven years with considerable success. So far, he agreed with the Author as to the advantage of impulse-every-revolution engines over those of the Otto cycle. The latter class had done admirable work, but could not be made of large size; and as yet, no Otto-cycle engine more than 100 IIP. had been made with a single cylinder; and at that power great difficulties had been encountered in practice. The exhaust-pressure was extremely high, and a great deal of power was lost there. A stroke of one of these large gas-engines was finished with an exhaust-pressure as high as the initial pressure of many steam-engines. It was little less than 50 lbs. per square inch at the end of the expansion-stroke of an Otto-cycle engine of large power. That feature would have to be improved before very large engines could be constructed. The question of starting gear had not been fully treated in the Paper. At present there were no gas-engines handled by levers, as was the case in many reversing steam-engines; he might therefore be permitted to say a few words upon starting gear. Self-starting gear was first introduced for gas-engines by Brayton, in 1876. Brayton's engine was the first to use flame impulse. Compressed air was stored in a reservoir, which was screwed up on stopping the engine at night, and the pressure from it was used for starting the engine in the morning. In 1881 he introduced a self-starter upon his engine; about 100 of them were put to work, and many of them were working satisfactorily at the present time. The second cylinder of the engine was so arranged that a pipe passing from the first cylinder carried the gases into the motor-cylinder. When the engine was stopping at night, the valve was closed, cutting off connection between the pump and the cylinder, thereby compressing the gases in the pump-cylinder through the valve into the steam-reservoir. When the engine was stopped at night, the reservoir was closed, and the valve was screwed down. It was welded throughout, with only one joint, and was so successful that it would stand for months with the valve screwed down, without any loss. In the morning, the crank was set over the centre, the starting-valve was opened, and the mixture passed into the cylinder and ignited at the igniting-valve, and the engine started at once. Messrs. Crossley had introduced a self-starter on a similar principle, using the products of combustion from the explosion-cylinder, and passing them into the chamber. A starter which had during the last few years made head-way was that introduced by Mr. Lanchester in 1890, of which many hundreds

Mr. Clerk.

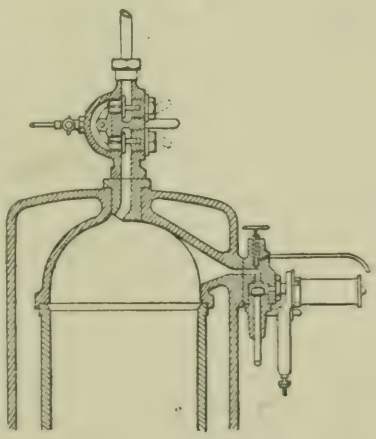
Mr. Clerk. were at work in the Otto and other gas-engines. The crank was set on the forward stroke, the combustion-chamber being filled with air; a little gas was introduced in order to form an explosive mixture. The gas flowed out from a peculiarly forward jet, and, as soon as it was formed, the roaring of the mixture burning at that jet showed that the charge in the cylinder was explosive. All that had to be done was to turn off the gas at the main and start it. The flame passed back, and the engine started. One difficulty about the starter was, that the pressure available was rather feeble if there was much stiffness about the engine, or about the belting, or anything connected with it. In 1891, Mr. Clerk had arranged a starter on another principle, which was now largely used in gas-engines. There was a chamber outside the cylinder connected with a check-valve. When the engine started, the crank was set off the centre as usual. The gas was turned on by a tap from the main, and flowed into the chamber, mingling with the air in the chamber and forming an explosive mixture; at the same time it flowed into the cylinder through an aperture. As soon as the mixture was sufficiently formed it ignited at the little jet. When it was observed, from the roaring of the flame, that the mixture was sufficiently explosive, all that had to be done was to turn the tap to close the gas-main, upon which the flame shot back and ignited. The flame so produced under atmospheric pressure, filled the cylinder, and forced the gases before it. It actually forced the explosive mixture through the check-valve and compressed it into the cylinder to about 50 lbs. per square inch before exploding. The mixture was therefore compressed in the cylinder by a preliminary explosion. In that way, instead of obtaining only the maximum pressure of 60 lbs. or 70 lbs., the full maximum pressure of an ordinary Otto explosion was gained. There was an average available starting-pressure of 85 lbs., and the pressure rose to 220 lbs. per square inch. Even if the whole line of shafting was coupled to the engine, it started without difficulty. That was the starter that Messrs. Crossley were using largely. There was a modification of it, in which, instead of a mixture being made by means of gas flowing into air, it was formed by a little pump, and was forced through the whole arrangement to fill the cylinder at atmospheric pressure. Those starters were found to be effective, and would start an engine of any size. One great advantage was that there was no storage of pressure, and starting could always be effected by merely turning a tap with the finger and thumb.

Mr. Fielding. Mr. JOHN FIELDING thought it desirable to mention another form

of starter, which, curiously enough, he had produced at about the same time as Mr. Clerk had produced his latest form of that apparatus, and apparently with similar results. There was, however, a difference between the two starters. He stored up pressure; and there was no difficulty whatever in maintaining it for an indefinitely long period. *Fig. 4* represented a starter applied to an engine of 100 I.HP., which had actually been in use every day for the last 6 or 8 months. In an engine of 20 HP. it had been working for 15 months. Compressed-air was stored in a reservoir by the action of the engine at about 60 lbs. per square inch. The crank was placed at an angle of 15°. There were two valves; one of which was opened by a lever, the gas being admitted much in the same manner as in the Lanchester starter. On entering, the gas was directed downwards, so as to drive out the air, and it then escaped by the igniting-port. The presence of a flame issuing from the pipe showed that the cylinder was fully charged with gas—not an explosive mixture. The compressed air was, by the reversal of a handle, introduced into the cylinder, where it mingled with the gas, forming an explosive mixture under a pressure of 50 lbs. or 60 lbs. per square inch. It was automatically ignited by the ordinary Bunsen tube at the moment a suitable mixture was formed. The impulse was indicated by the diagram, *Fig. 5*. In that way the engine might be started, even though connected up to a considerable amount of shafting and belting, and the difficulty which had previously existed in starting engines under a load or a partial load disappeared. That was a step in advance towards using gas-engines of very large powers. He did not entirely agree with the Author that, in the near future, engines of the consecutive-impulse cycle might be expected to solve the question brought forward in the Paper. He was inclined to pin his faith, for a considerable period at any rate, to the Otto cycle. The consecutive-impulse cycle introduced many difficulties; one of which was the very question of free ignition, which had been mentioned as a special fault of

Mr. Fielding.

Fig. 4.



Mr. Fielding. the Otto cycle. He was inclined to expect modifications of that cycle as the next step; and to think that some time in the future engines of the cycle referred to by Mr. Clerk might be forthcoming for large powers; but so far, there was no indication of the existence of any such engines. The Otto cycle gave only one impulse in four strokes, but it was merely a question of multiplying the cylinders for an impulse every revolution. His opinion was that this appeared to be the most satisfactory way of accomplishing the result. There was one point in the engine shown in Fig. 2, Plate 1, which he thought objectionable—the pistons worked opposed to each other on the same crank, the result being that there were two impulses in one revolution without any in the next. He thought it would be much better if the cylinders were so arranged as to give an impulse every revolution. The engine to which he had referred had the practical disadvantage

Fig. 5.

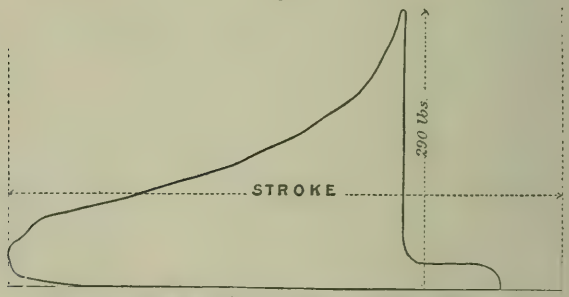


DIAGRAM FROM 12-HP. "FIELDING" GAS-ENGINE.
Scale, 150 lbs. per square inch. Average pressure, 99·5 lbs. per square inch.

of opposing thrusts upon the bearings. As had been shown in the case of the Willans and other single-acting engines, it was of great advantage to so arrange the thrusts that they might be all in the same direction, and that could be easily done in the Otto engine. Fig. 2, Plate 1, showed a compact form of engine, but he should like some information with regard to the construction of the connecting-rod end bearing on the crank-pin. It appeared to him that the only form of connection that would meet the conditions, would be something like Brotherhood rings inserted at the ends of the rods, which, although suitable and permissible in a steam-engine, where the thrusts were all in the same direction, did not appear to him to be at all right in a gas-engine, where the crank had to pull the piston forward during the charging stroke. Another point had been raised with regard to the presence

of the products of combustion in the cylinder. From his experience he was quite sure that an economy of 15, 20, or 25 per cent., might be obtained if the products could be entirely removed. That formed a modification of the Otto cycle to which he was at present directing attention, and which he thought might be accomplished. At the present time the difficulty was to a certain extent met by the adoption of high compression, by which means the capacity of the combustion-chamber was reduced, and therefore also the amount of products of combustion were left in it. If the products were left in, the higher compression that could be obtained the better, as it made the ignition more certain. Another incidental advantage of high compression was that they had a rounded corner diagram as shown in the Rouen diagram Fig. 12, Plate 2, and also in Fig. 16. This caused the pressure to be applied gradually to the crank-pin, instead of being a sudden shock as in the diagram Fig. 7, where a lower compression obtained. On the question of governing, great stress had been laid on what was called a defect—and it was, no doubt, to some extent a defect—of gas-engines, viz., irregularity of speed. But he could not help thinking that much more stress had been laid upon that point than was justifiable, seeing that lights were driven with perfect steadiness direct from gas-engines without accumulators. That was obtained by different methods from those applied in steam-engines, but as long as the results obtained were satisfactory, that was all that could be asked for. At the same time, he was willing to admit that improvement should be aimed at in future. Mr. Fielding.

Mr. James Atkinson had come to the conclusion ten years ago, that the residuum in gas-engines such as the Otto was a very prejudicial substance, and, in the year 1885, he had invented the "Differential" gas-engine, which drove out the whole of it. It was interesting to note that that engine, a 2-HP. gas-engine, gave 1 brake HP. with about 26 cubic feet of London gas. That would compare favourably with the particulars of the 2-HP. Otto engine given in the Paper, which had been stated to require 32¾ cubic feet for 1 brake HP. There could be no doubt that, as shown by the analysis of waste gases given in the Paper, where there was oxygen and carbonic oxide present in the exhaust, the Author's argument as to the large number of molecules of inert gases preventing the oxygen and carbonic oxide from coming together and burning thoroughly, constituted one reason why the residuum should be driven out. Mr. Atkinson did not know that it was essential to drive the whole of it out of Mr. Atkinson.

Mr. Atkinson. the gas-engine cylinder, but it was absolutely necessary to keep it isolated from the charge by pure air. Some pertinent remarks had been made upon that question by the late Professor Fleeming Jenkin, in his lecture on "Gas- and Caloric-Engines,"[1] and in that sense he did not know that the residuum would do any great harm in the gas-engine cylinder. A few years after the invention of the "Differential" engine, he had brought out the "Cycle" gas-engine. That had the same theoretical cycle as the "Differential" engine, but it was put into a different form; and he presumed that it was within the knowledge of most of the members present that, at the Society of Arts trials, it had given 1 brake HP. with less gas than any other gas-engine in public trial. It had maintained its superior economy, and was at present, he believed, the most economical engine built, with one exception, viz., his "Utilite" engine. This had practically the same cycle as that of the "Cycle" engine, and its diagram was almost identical with that in Fig. 17, Plate 2. He believed it would be an essential point in gas-engines of large powers to reduce the terminal pressure. In the "Cycle" engine diagram, Fig. 17, the terminal pressure was about 14 lbs. per square inch, and all the additional work from the expansion of about 40 lbs., which it would have been had it only expanded to the original volume, was obtained, with the great advantage of quiet exhaust. The same thing took place in the "Utilite" engine. It was possible, with a slight alteration of working-gear, to make a "Cycle" engine leave the residuum in identically the same way as the Otto engine left it; the best result he had obtained with that engine (the first "Cycle" engine constructed) with the residuum left in, was 1 brake HP. for 25·7 cubic feet of gas per hour. The same engine, with a slight alteration in the gear, subsequently tested by Professor Unwin, gave 1 brake HP. for 22·11 cubic feet of gas per hour—showing a saving of 3·6 cubic feet by simply getting rid of the residuum. The diagram had been taken from an engine of 15 nominal HP., but under unfavourable conditions as regarded economy. The engine was driving deep-well pumps coupled direct at 86 revolutions per minute, which was the most economical speed for gas-engines; notwithstanding that, and the fact that the engine was of small power, it gave the economical result stated in the Paper. He had not been able to procure the figures officially, but had obtained them unofficially. The engines were put in to replace a horizontal steam-

[1] "Heat in its Mechanical Applications," Inst. C.E., Sess. 1883–84, p. 101.

engine with automatic cut-off driving geared deep-well pumps. The fuel consumed by the steam-engine for a certain amount of work cost £400 per annum. With Dowson plant and the gas-engine, the same work was now done for £90 per annum. One HP. was effected with about 1·68 lb. of fuel. He had had a small plant working for about 6 years at Wimborne Minster water-works. It was only a 6-HP. engine, and there 1 HP. was effected for 1·7 lb. of coal. It was impossible, with steam-plant on such a small scale, to do with less than double that amount of fuel; and probably three or four times as much would be required. He had been trying for the last ten or twelve years to get one impulse per revolution, and he had never yet made an engine that was not intended at any rate to give that; although he had not always succeeded. The engines made by him even ten years ago, many of them working at the present day, were all capable of giving an impulse per revolution; and it was an essential feature in any future large engine, because with one cylinder and engine the same thing could thus be done as with a twin engine on the Otto cycle. Mr. Atkinson infinitely preferred the engine shown in Fig. 2, Plate 2, to the ordinary coupled twin engine, which had three bearings, and on the outside of each outer bearing a heavy fly-wheel. It was impossible for the middle bearing to wear down the same as the outside bearings; and, in consequence, the shaft bore on the middle, springing backwards and forwards every time it revolved on the middle bearing; and, sooner or later, the crank-shaft must break, unless the bearing was continually lined down and kept on a level with the two outer bearings. Increased expansion was essential in a large engine, because economy was thereby ensured, and there was less trouble with the exhaust. He might be allowed to explain the details of the "Utilite" engine. The crank-pin was entirely enclosed, and as the piston made the compression-stroke it drew pure air only into this chamber; it was impossible to get an explosive mixture in that portion of the engine, which was a matter of vital importance. As the working stroke was made, the air was slightly compressed, to, say, 4 lbs. per square inch above the atmosphere. At the end of the working stroke the exhaust took place, and, as the pressure fell in the working-end of the cylinder, air from the other end passed round through the self-acting valve, and flushed everything out, or, at all events interposed pure air between any small amount of residuum that might remain and the in-coming charge. When the flushing was complete, a small

Mr. Atkinson.

Mr. Atkinson. pump on the side of the engine drove in a mixture of gas and air, which was too rich to ignite, so that it was impossible for ignition to occur in the pump. A slight further admixture of air, however, rendered it explosive. During the time that this was taking place, the piston came back and compressed the charge, ignition took place, and the working stroke was made. That applied to small engines. But for engines of above 2 HP., he adopted the principle of continued expansion. The piston passed the exhaust-port before the end of the working-stroke. There was a small plug-valve that need not be tight, by which the pressure was retained in the cylinder until the stroke was completed. There was a slight kink in the diagram, at the point where the piston passed the opening, showing a drop through the pressure filling that space, but it was retained in the cylinder up to the end of the working-stroke; then the plug-valve was opened and the exhaust took place. Observations had been made as to the advantages of a heavy fly-wheel; but it was a serious thing to have to drive it, and to have to stand the wear and tear caused by it. The mechanical efficiency of the engine fell most materially, as had been proved by Professor Thurston. Almost the heaviest loss by friction in a steam-engine, was the mechanical power required to turn the fly-wheel on the crank-shaft, and the heavier the fly-wheel, the greater the loss, and of course the wear and tear was similarly increased. The diagrams, Figs. 11, 13, and 14, were evidently not correct; but, in all probability, the experimenter who made the tests was to blame. Mr. Atkinson had experimented a great deal upon later ignition, and it was, to a certain extent, advantageous to have the ignition rather late, particularly if there was increased expansion. But he had always found that, with a late ignition, the expansion-line of the diagram ran high.

Professor Capper. Professor D. S. Capper observed that several speakers had referred to the absence of any correct analyses of the exhaust-products of the gas-engine. He had made one or two tests lately on a 7-HP. (nominal) engine, which had been put down in his laboratory at King's College. He would submit what he thought to be approximately correct analyses of the exhaust-products.

Analysis of London Gas before Ignition.

CH_4 . . .	31·5	CO . . .	7·7
C_2H_4 . . .	2·5	N_2 . . .	3·06 (by diff.)
C_4H_8 . . .	2·6	CO_2 . . .	1·0
H_2 . . .	51·2	O_2 . . .	0·44
Total	100·00		

The ratio of air to gas, calculated on the assumption that the temperature of the gas after admission was somewhat higher than the exit temperature of the jacket-water, was 9·187 to 1. Calculating from this ratio, and allowing for the oxygen necessary to convert all the hydrogen into water, the dry exhaust-products should be— Professor Capper.

CO . . .	nil	O_2 . . .	8·94
CO_2 . . .	6·45	N_2 . . .	84·61 (by diff.)
Total	100·00		

An analysis of a sample taken as near as possible to the exhaust-valve, gave (neglecting moisture)—

CO . . .	nil	O_2 . . .	6·14
CO_2 . . .	6·76	N_2 . . .	87·1 (by diff.)
Total	100·00		

It would be seen that the CO_2 was extremely close in the two statements, practically identical. The excess in oxygen was probably accounted for by the fact that there were several miss-fires per minute, and the air then passing through the cylinder was not included in the ratio of air to gas, as calculated. The samples for the analyses were taken during a three-quarter power trial, made in December, 1892. The actual efficiency obtained in this trial was 27·4 per cent. of the theoretical efficiency, and the mechanical efficiency of the engine was 83 per cent.

Mr. John Head said that Mr. Foster, in speaking of the gas-producer, had made a remark which he understood to mean that in the original form of Siemens gas-producer, water was not used. He had lately seen the same remark made in several papers in England and abroad; but it was not correct. From the earliest days of the Siemens regenerative gas-furnace, more than 30 years ago, water or water-vapour was always decomposed by the fuel in the producer. Notwithstanding that the producer was designed to burn coal and had to distil the hydro-carbons it contained, a certain quantity of water-vapour was also decomposed. The water for that purpose was introduced under the grate. Subsequently, Sir William Siemens proposed to use steam, and that had been adopted in one or two works; it was not largely applied, however, in those days, because manufacturers could not be induced to erect boilers to work in connection with furnaces. Mr. Head.

Professor George Forbes had been referred to by the Author as having spoken of the value of introducing gas in central-station Professor Forbes.

Professor Forbes. lighting by electricity. He had lately had occasion to go into that question pretty fully in connection with authorities who had taken over town gas-supply, to see whether the loss which might be expected to arise from introducing electricity might not be compensated, to a great extent, by using the gas for purposes of motive-power. The prime cost of gas-engines was, of course, a serious matter, as was also their want of steadiness, and, hitherto, the absence of a thoroughly reliable starter. Those were all points against the use of the gas-engine. With gas distributed as it was through towns, there were causes which would render it the most economical system to introduce; having small sub-stations distributed about the town to supply the net-work of conductors. That would enable a large reduction to be made in the cost of copper in the conductors. It had another advantage, the great demand for electric light being only for a few hours in the evening, considerable expense in fuel was involved in banking the fire and in raising steam, and this was entirely eliminated by the use of the gas-engine. In the Kensington and Knightsbridge station, he believed the proportion of fuel required in ordinary working, compared with what was required when working steadily at constant load, was about 5 to 3; and it appeared that the working expenses in certain cases, with gas at 2*s.* 6*d.* per 1,000 cubic feet, might actually be less by using gas-engines than by using steam-engines. But at present, the absence of very powerful gas-engines, and certain inconveniences attaching to their use, interfered with their recommendation. His object was to point out to engineers that they were on the verge of having to consider cases in which it was more economical to use gas for distributing power to sub-stations, than to spend money in the street feeders.

Mr. Preece. Mr. Thomas Preece wished to lay before the members a few particulars relating to the central electric-lighting station constructed by him at Morecambe. He believed that that station was the first in the country to demonstrate the feasibility of generating and distributing electric energy from a small central-supply on a paying scale by means of gas-power. With reference to the diagrams, *Fig. 6* gave particulars of the current generated, the current sold, and the consumption of coal and coke, and *Fig. 7* gave the nature of the supply for one week ending the 3rd December. This formed a daily record of 8 working hours, the stand-by hours being 16; the waste in the generator was under 3 lbs. of anthracite per hour. The station was worked under exceptionally trying conditions, as the working hours were so few in

relation to the stand-by hours. In fact, he believed it would be impossible to work such a station profitably with steam-power; as the loss from the boiler, raising and keeping up steam, would be a serious item. With Dowson gas, the generator could be started or stopped at a few moments' notice, whenever required. With reference to the cost per kilowatt, although the anthracite cost 24*s.* a ton, the total cost of fuel per unit generated was only 0·61*d.* That compared favourably with the results of even large central-stations; though he need scarcely add that a strict comparison between a small central-station, such as he had described, Mr. Preece.

Fig. 6.

MORECAMBE.

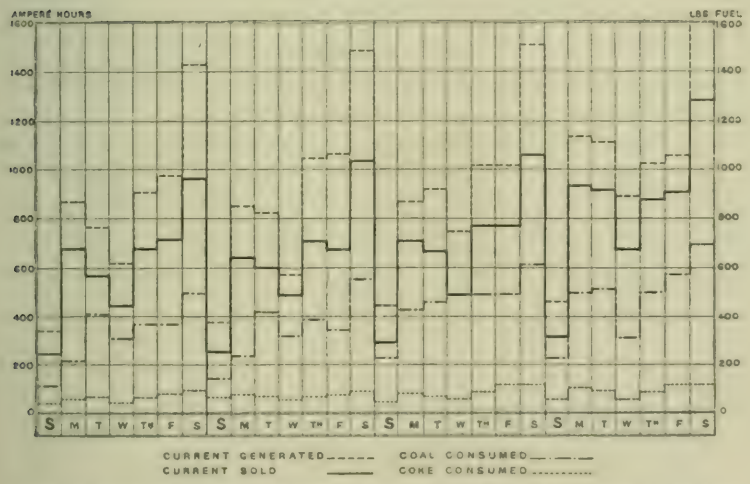


DIAGRAM SHOWING CURRENT GENERATED AND SOLD, AND COAL AND COKE CONSUMED DURING TWO WEEKS IN OCTOBER, AND TWO WEEKS IN DECEMBER, 1892.

and a large central-station, could not be justly instituted. The problem he had been trying to solve was how to generate and distribute electricity on a paying basis for small towns and villages and scattered areas, so as to supply both light and power at a price which would ensure public support. Several speakers had referred to the governing and starting of gas-engines. He employed neither governor nor self-starter, but started and governed the engines electrically. Details of the results attained at Morecambe were given in the Table appended.

Mr. Preece.

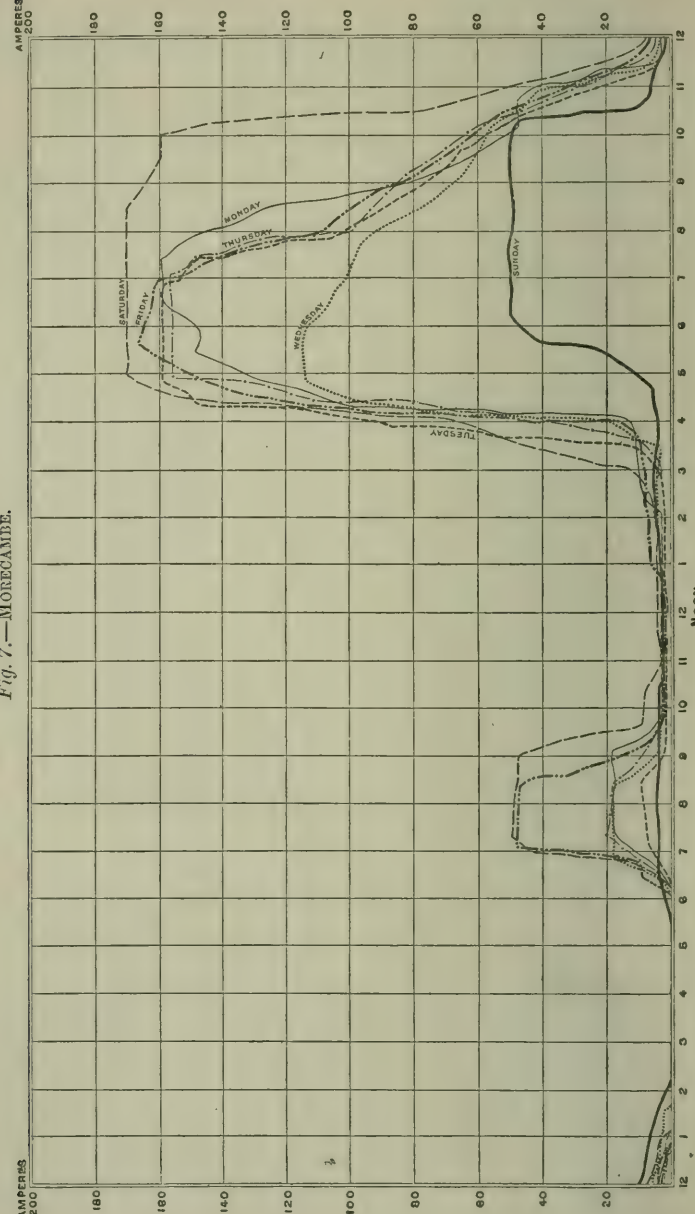


Fig. 7.—Morecambe.

Diagram showing Hourly Output of Current sold each Day for the Week ending 3rd December, 1892.

Mr. Preece.

MORECAMBE ELECTRIC-LIGHTING STATION.

	Date.	Hours worked by one or more Engines.	Hours when Generator standing.	Current generated.	Current sold.	Fuel Consumed in Pounds per Day.		
	1892.	H. M.	H. M.	Watts.	Watts.	Coal.	Coke.	Total.
S	Oct. 23	2 25	21 35	44,500	30,000	125	55	180
M	„ 24	7 40	16 20	128,410	81,600	230	75	305
Tu	„ 25	7 55	16 05	123,950	69,600	425	80	505
W	„ 26	6 50	17 10	98,690	56,400	320	50	370
Th	„ 27	8 10	15 50	136,900	79,200	375	70	445
F	„ 28	8 15	15 45	137,600	86,400	375	80	455
S	„ 29	9 55	14 5	188,000	116,400	500	105	605
S	„ 30	3 30	20 30	50,550	28,800	130	60	190
M	„ 31	7 40	16 20	127,440	79,200	245	75	320
Tu	Nov. 1	8 10	15 50	127,100	72,000	450	90	540
W	„ 2	7 0	17 0	96,180	58,800	325	60	385
Th	„ 3	9 45	14 15	156,490	85,200	400	75	475
F	„ 4	11 50	12 10	152,890	82,800	350	90	440
S	„ 5	11 30	12 30	197,050	124,800	550	105	655
S	„ 20	3 15	20 45	57,750	36,000	250	60	310
M	„ 21	7 45	16 15	130,120	86,400	440	100	540
Tu	„ 22	8 30	15 30	138,230	80,400	480	90	570
W	„ 23	8 35	15 25	113,280	60,000	400	100	500
Th	„ 24	9 0	15 0	152,730	93,600	520	100	620
F	„ 25	9 5	14 55	142,980	93,600	520	140	660
S	„ 26	11 0	13 0	198,800	127,200	635	140	775
S	„ 27	3 30	20 30	61,350	39,600	260	60	320
M	„ 28	8 20	15 40	156,160	112,080	520	120	640
Tu	„ 29	8 30	15 30	153,050	110,400	520	110	630
W	„ 30	8 45	15 15	132,355	80,880	380	70	450
Th	Dec. 1	9 0	15 0	153,230	103,200	500	100	600
F	„ 2	8 45	15 15	160,110	108,000	575	130	705
S	„ 3	11 35	12 25	233,150	154,800	700	130	830
Totals		226 10	445 50	3,749,045	2,337,360	11,500	2,520	14,020
Average per day		8 5	15 55	133,898	83,480	410·7	90·0	500·7

General Result.

Total fuel consumed = 14,020 lbs. = 3·74 lbs. per kilowatt generated.
Total current generated = 3,749 kilowatts.

Mr. KILLINGWORTH HEDGES desired to make a few remarks on the central-station at Dessau, mentioned in the Paper, which he had visited. It was a station driving 4,000 lamps. He was informed that the gas-consumption was only 25 cubic feet per indicated HP., to which it had been reduced from 31 cubic feet when the station was opened. The quantity of water used had not been given by the Author. It seemed to Mr. Hedges to be very high—14 gallons per HP.—but he believed it had lately been reduced. Mr. Hedges.

Mr. Hedges. Part of this water was used for cooling the dynamo-bearings, a practice which appeared to be common on the Continent. The plan of working showed how necessary it was to use accumulators in connection with gas-engines, because there were at first, at Dessau, a number of small engines which were afterwards replaced by engines of 60 and 120 HP. Engines of 60 HP. were used to charge the accumulators during the day, and at night the accumulators worked with the 120-HP. engines. The batteries were of the Tudor type, which he believed were not well known in this country, but he had been told that their average efficiency throughout the year was 78 per cent. In spite of that, the station seemed to be a failure, the financial result being indifferent; and he did not think there were any other stations of the kind being put up in Germany. It was owned by the Gas Company, and therefore there was no reason why the consumers should use electric light more than gas; in fact, they used gas a great deal during the winter on account of the cold. At Rheims he visited another smaller station, on similar lines, using Khotinsky accumulators. There was one point in the Author's summary which he could not quite understand, where he said: "When town-gas is used, no boiler and no firemen are required, and there are no ashes to remove; less ground space is needed; no accumulators are required, except such as may be necessary to equalize the load of the engines, and to provide for a small amount of storage." That did not seem to accord with what the Author had previously shown as to the best results having been obtained with accumulators. Generally, the price of electric light on the Continent was low, especially where water-power was used. He had corresponded with engineers interested in works at Stuttgart, who told him they were generating electricity at $1\frac{3}{4}d.$ per Board of Trade unit, and were selling it for 51-watt lamps at $\frac{1}{4}d.$ per lamp hour, for 1,500 candle-power arc-lamps at $1\frac{3}{4}d.$ per lamp hour, and for motors at $1\frac{1}{2}d.$ per HP. per hour.

Mr. Beaumont. Mr. W. Worby Beaumont protested against the notion that the Otto cycle was the only one that gas-engine builders should follow. That idea was doing a great deal of harm; and those who, like Mr. Atkinson, were trying to get more out of engines of a given size, should be encouraged in that endeavour. The notion that an engine should work for one stroke, and then run idle, as one might call it, for three strokes, was ridiculous. If a steam-engine were offered, giving work during one stroke, lying idle during three strokes, except to work a feed-pump, such an engine would be rejected. That was much what was done with the gas-engine; and,

since it had already been shown to be possible to make an engine which would at least give one impulse per revolution, he thought that should be encouraged, rather than the falling back upon the Otto cycle, which seemed to be prevalent. The Lenoir gas-engine was made 27 years ago, and it gave two impulses at every revolution. He was engaged in the construction of that engine, and remembered that it worked fairly well; though the method and period of igniting the gas and the want of compression, prevented it from being a practical success. There was not, however, any reason why either that or the Otto system should be used. It might be of interest to record the sizes of the Lenoir engines made some 23 years ago. They were :— Mr. Beaumont.

Nominal HP.	Diameter of Cylinder.	Stroke.
	Inches.	Inches.
½	5·500	9·00
1	7·125	11·50
2	8·750	15·75
3	10·250	18·00

A comparison of the figures with those of the best modern engines gave some idea of the great improvement that had been made since that time. As two impulses were given in every revolution by the Lenoir engine, it was about four times the size of any engine made at the present time; and if the lines followed by Mr. Atkinson and others could be improved upon, it might be hoped that a gas-engine could be made suitable for electric lighting. It would, however, have to work otherwise than by the Beau de Rochas cycle. The use of heavy fly-wheels in the Otto cycle caused a difficulty in starting. The starting of large engines could be effected by small barring gas-engines, and it should be mentioned that some of the explosive starters were not good things. Only recently one came to pieces, and endangered the lives of those who were near to it.

Mr. Dowson, in reply, said that with regard to gas-engine design, he had raised the important question of abandoning the present usual practice of retaining the products of combustion in the cylinder, especially when generator-gas was used. No speaker had opposed his views. On the contrary, they had been supported, and Mr. William Foster had stated that he had no confidence in complete combustion being obtained, if the gas to be burnt was largely diluted with products from a previous charge. Since the Paper had been written, he had discussed the question with several competent persons, and, so far as he could judge, it was admitted Mr. Dowson.

Mr. Dowson. that the removal of the products was right in principle. As it was especially important for generator-gas, on which the economical working of large engines depended, the question now resolved itself into one of devising means for carrying out the principle in a good mechanical way. With reference to the successive impulses of the different types of engines illustrated in *Fig. 3*, that comparison would have been more exact if Mr. Hartley had compared a double-acting Kilmarnock engine with an Otto engine having two single-acting cylinders. The impulses of the two engines would then have been identical. The Kilmarnock engine had the Otto cycle, and each end of the cylinder required a separate ignition, and as many valves as a single-cylinder engine. Practically, therefore, the comparison lay between an engine having two single-acting cylinders and one with a double-acting cylinder. It was an interesting development, and he wished Mr. Hartley had been able to give the results of working a large engine of that type. He had been stated by Mr. Dugald Clerk to have expressed the belief that an impulse at every revolution would necessarily entail a larger consumption of gas per HP. What he had said was that "This may involve an auxiliary pump, and consequently an increase in the friction of the engine." He did not say definitely that it would involve a greater consumption of gas, as that would depend upon the design of the engine. The Day engine was ingenious, and he wished it every success, but, without entering into details, he was sure it would have to be greatly modified before it could be worked for large powers. Moreover, he felt strongly that it was dangerous to confine a large body of explosive mixture in a chamber which might at some time have direct communication with the cylinder. A spark or a little flame left in the cylinder at the wrong moment might cause a mishap; and, speaking generally, he thought it imperative in a gas-engine of moderate size, that there should be no large storage of an explosive mixture either in the engine itself or in connection with it. With regard to the four Rouen diagrams, Figs. 11, 12, 13, and 14, Plate 2, he had the originals, and they had been carefully reproduced to the scale given. Some doubt had been thrown upon the indicator used for Figs. 13 and 14, but he was not responsible for that. The diagrams were taken in a trial made by Professor Witz, who was a careful experimenter; Mr. Dowson was present during the trial, but he had nothing to do with the instruments used. As to starters for gas-engines, they were no doubt important features, but it was unnecessary to discuss their details, as they

had not much bearing on the subject of the Paper. With respect to fuel for the generator, Mr. Lea wished to know what fuel could be used when anthracite was too dear; the answer was, ordinary gas-coke of small size. Several examples of that were given in the Paper. In connection with products of combustion, Mr. William Foster had expressed the desire of all concerned in the working of gas-engines, when he spoke of the importance of analysing the exhaust gases, but, as Professor Kennedy had pointed out, they were difficult to collect, owing to their high temperature and pressure. Moreover, if they were allowed to cool, there was condensation of water-vapour, which absorbed some of the carbonic acid. The analysis given at the end of Appendix F was a precise copy of that sent to him in an official document, and, although he felt it needed some explanation, he thought it best to insert it in the Paper as he had received it. With respect to the products of combustion from a steam-power station, Mr. Graham Harris had referred to "the fearful results that must ensue from sending the large amount of high-pressure steam," &c., given off by the various high-pressure steam-engines at work in London, into its atmosphere. Mr. Dowson could only suppose that Mr. Harris had mis-read or had not understood what he had said. On page 23 of the Paper, Mr. Dowson had estimated the amount of steam discharged into the air from stationary steam-engines in London at 9,000 tons, or something like 400 million cubic feet, and the carbonic acid at 4,400 tons, or about 80 million cubic feet, each working hour. He had then stated that, at a moderate computation, the existing metropolitan electric-lighting stations discharged about 1,750,000 cubic feet of carbonic acid, and about 10,000,000 cubic feet of steam into the air every hour of maximum output. In commenting on these figures he had said: "When these facts are realized, the question will arise, sooner or later, whether such enormous volumes of steam and carbonic acid are to be sent into the air, regardless of the consequences to the inhabitants." He had never said that the steam and carbonic acid from any one station would affect the whole of London. He might just as well have said that one smoky chimney would obscure the sky all over London. But he did say that just as one smoky chimney was a nuisance in its immediate neighbourhood, so many smoky chimneys would affect London, or any other large city, generally; and if London were eventually to be lighted throughout with electric light, the vitiation of the air by many steam-power stations should be considered. [Mr. Harris asked how that was to be cured by gas-engines.] With respect to the

Mr. Dowson.

Mr. Dowson. consumption of town-gas in engines, the Managing Director of the Dessau electric lighting station had sent him the following detailed returns for 30 days in December, 1892.

RETURNS OF THE ELECTRIC-LIGHTING CENTRAL-STATION, DESSAU, DECEMBER, 1892.

Date.	Number of Working Hours.	Current Produced.	Current Produced each Hour.	Town-Gas Consumed.		
				Each Day.	Each Hour. (Average).	For 100 Watts.
		Watts.	Watts.	Cubic Metres.	Cubic Metres.	Cubic Metres.
1	4·25	296,800	69,835	340·8	80·18	0·1114
2	6·08	428,400	70,460	502·7	82·68	0·1173
3	4·55	336,400	73,934	385·8	84·79	0·1146
4	5·70	403,200	70,736	475·5	83·42	0·1179
5	5·00	344,800	80,960	384·2	76·84	0·1114
6	5·70	406,400	71,298	448·8	78·75	0·1104
7	5·33	378,400	70,994	420·6	78·91	0·1111
8	4·58	178,800	39,039	278·0	60·69	0·1554[1]
9	5·47	324,000	59,232	405·6	74·15	0·1251[1]
10	3·75	263,600	70,293	269·5	71·86	0·1022
11	4·93	346,800	70,344	348·9	70·77	0·1006
12	5·97	418,000	70,016	516·5	86·51	0·1235
13	5·40	384,800	71,259	454·0	84·07	0·1179
14	4·50	321,200	71,155	368·8	81·95	0·1147
15	4·25	289,200	68,284	346·0	81·41	0·1196
16	5·33	386,800	72,570	406·2	76·21	0·1050
17	4·33	301,200	69,561	324·0	74·82	0·1075
18	4·75	313,600	66,020	381·4	80·29	0·1216
19	6·08	424,400	69,802	519·3	85·41	0·1223
20	5·95	408,000	68,571	493·0	82·85	0·1208
21	4·75	347,200	73,094	403·0	84·84	0·1160
22	5·90	439,600	74,508	498·1	84·42	0·1133
23	5·75	405,200	70,469	482·3	83·87	0·1190
24	4·70	326,000	69,361	393·4	83·70	0·1207
25	5·21	370,400	71,094	426·0	81·76	0·1150
26	4·75	346,400	72,926	394·3	83·01	0·1138
27	5·92	424,800	71,756	490·3	82·80	0·1154
28	..	..	..	..	..	..
29	4·80	331,200	69,000	394·5	82·18	0·1191
30	5·90	443,200	75,118	483·5	81·85	0·1090
31	3·70	268,000	72,432	287·2	77·62	0·1071
	153·3	10,656,800	69,516	12,322·2	80·38	0·1156

Average production with 1 cubic metre = 864·8 watts.

The average of the whole month gave the following results:—

Working-hours per day. . . . . = 5·11
Current generated per day. . . . = 355,226 watts.
„ „ „ hour . . . = 69,516 „
Town-gas consumed per hour . . = 2,839 cubic feet.
„ „ „ kilowatt hour = 40·82 cubic feet.

[1] Something wrong at the dynamo.

Mr. Dowson.

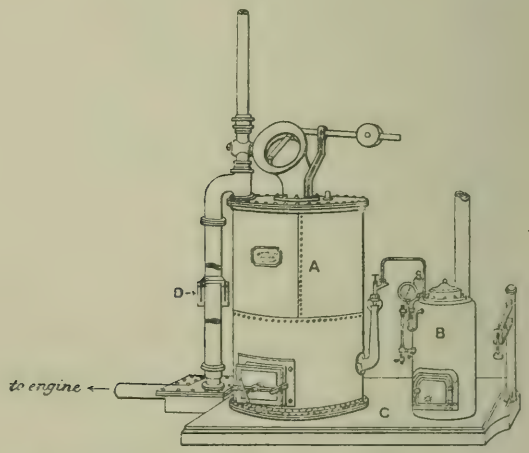
As to the use of accumulators, he thought there was less need for them when the engines were driven with town-gas, instead of steam power, because the large holder at the gas-works provided ample storage. At the same time he believed that even with town-gas a few accumulators would often be desirable to equalize the load on the engines. As regards the Schwabing installation, he was able to give the following returns, based on the average of a month's working: Hours worked per day, 7; current produced per hour, 200 amperes by 125 volts; anthracite consumed per day in generator, 250 kilometres, and coke consumed in boiler, 60 kilometres. This averages a little under 4 lbs. per kilowatt-hour.

The 39 cubic feet per kilowatt-hour given in the Paper was not the average consumption, but the consumption during a trial. The figure now given was the average taken over the whole month of last December. The average annual consumption of water per HP. (including that used for cooling the dynamo bearings) was 4½ gallons, and not 14 gallons, as Mr. Hedges supposed. He had purposely avoided entering into the financial affairs of the installations he had referred to, but as Mr. Hedges had spoken of the Dessau station as a failure, he was authorized to state that, although the electric lights were used an average of only 197 hours each in a year, the plant has been maintained in good order, and a profit of 5 per cent. has been earned on the capital invested. With reference to Mr. Kapp's remarks, the consumption of gas at Tussaud's Exhibition, given in Appendix K, was precisely that given to Mr. Dowson some months ago. He was informed that since then some alterations had been made to the plant; and he was glad to learn from Mr. Kapp that the average consumption was now as low as 33·4 cubic feet per unit in winter, and 36 cubic feet in summer. He had stated in the Paper a belief that the late Sir William Siemens was the first to draw attention to the fact that when illuminating gas was burnt in a gas-engine to drive a dynamo, much more light was produced electrically than could be produced by burning the same quantity of gas in burners in the usual way. Evidence to that effect had been given by the late Sir William Siemens in 1879; but Mr. Dowson had since learnt that on the 22nd January, 1878, during the discussion upon a Paper read before the Institution,[1] Dr. John Hopkinson had called attention to the interesting fact referred to; and, so far as he was aware, that was the first record of such a statement. With respect to the consumption of fuel with generator-

[1] Minutes of Proceedings, Inst. C.E., vol. lii. p. 69.

Mr. Dowson. gas in a central station, the best instance was certainly that of Morecambe, as the returns now given by Messrs. Andrews and Preece were of a thoroughly practical nature. He regretted that when his Paper was printed he had not been able to include all the details now received; but the dates would show that he could not have given more than those which appeared in Appendix H. The diagram, *Fig. 7*, showed how variable was the daily output, and what a long stand-by period there was each day; so that the mean load-factor of the last week, which was the best, was only 18. The returns showed that the plant only worked an average of about 8 hours, and stood 16 hours in every 24. On Sundays it stood about 21 hours. As to stand-by loss, Professor Kennedy

Fig. 8.



had asked for confirmation of the figures given in the Paper; and, in addition to what had been stated by Mr. Thomas Preece for Morecambe, he would give the following particulars:—Some time ago he had worked a generator placed on a weighing-machine, *Fig. 8*. The gas was taken to an engine under trial; and, by having a hydraulic joint perfectly free in the pipe leading from the generator, gas was made continuously, while at the same time it was possible to tell at any time what was the actual weight of fuel converted into gas. The generator was worked with anthracite, and served about 32 brake HP. After the trial, the generator was left on the weighing-machine with a fire in it, but without draught, for 18 hours, in the month of November, and during that time the waste of coal was 18 lbs. On another

occasion at Openshaw, a generator of about the same size had been worked in a similar way with coke, and, after the trial, it was left on the weighing-machine in the open air, in November, for 17 hours. During that time, the waste of coke was 60 lbs., or about $3\frac{1}{2}$ lbs. per hour. At Chelsea the generator referred to in the Paper served about 150 I.HP., and 3 tests had shown that the waste of anthracite during the time of standing was 6 lbs. to 8 lbs. per hour. At Openshaw there was a still larger generator, worked with anthracite, which served between 250 and 300 I.HP., and Messrs. Crossley had just sent him the following returns relating to it: On the 19th inst. the working of the generator was stopped at 8 P.M. and started again at 5 A.M. next day. The waste was 69 lbs. in 9 hours, or 7·6 lbs. per hour. On the 20th inst. the generator was stopped at 8 P.M. and started at 5 A.M. next day; the waste being 5·1 lbs. per hour. On the 21st inst. the generator was stopped at 2 P.M. and started again at 7 A.M. on the 23rd inst.; the waste being 3·9 lbs. per hour. A slight current of air was allowed to pass through the generator to keep the fire alive, and as that was not always constant, the waste of fuel necessarily varied somewhat; but it was evidently trivial compared with the stand-by loss of a steam-boiler for the same horse-power. With regard to the consumption of fuel with steam-power, Mr. Lea had stated that the company which produced the largest quantity of electricity, consumed about $9\frac{3}{4}$ lbs. of coal per unit sold. The trial made at the Electricity Supply Company's station and published in the *Engineer* of the 9th of September 1892, gave the fuel-consumption as equal to about 11·2 lbs. per unit generated. On the other hand, Professor Kennedy had thought it well to base his remarks on his present mid-winter consumption of 5·3 lbs. per unit sold; although as he had fairly stated, that was considerably below the average. Other returns showed still greater differences, but from none of them could it be determined precisely what excess of coal was used when the engines were running under light loads, or when some of the boilers were standing. The conditions of working were no doubt complicated, much more so than might at first sight appear; and before writing the Paper he had done his best to ascertain the losses referred to. Fortified with a good introduction, he had asked the engineer of a well-known metropolitan company for that information, and the engineer said he had not got it and had not the time to find it out. He had applied to a second engineer, who replied that he was not allowed to give such information for publication. He had then written specific questions to a third, who had merely replied with general state-

Mr. Dawson.

Mr. Dowson. ments, and did not answer a single question. Rightly or wrongly, he had concluded that their results were so bad that they did not wish them to be known. The loss of stand-by boilers had been estimated by Professor Kennedy at 10 per cent. of the total consumption in all the boilers; and Mr. Crompton had lately told him that, although he did not know precisely the boiler-loss at his stations, he believed it to be about the same. No one else had given information on that important point, and it would be especially interesting to know what was the actual loss of that kind at a station where there were no accumulators. It had been stated by Professor Kennedy that any engine (gas or steam) consumed for each useful HP. about 40 per cent. more fuel under half-load than under full load. Seeing that a gas-engine when governing cut off gas entirely, whereas a steam-engine when governing took in steam at every stroke—although in diminished volume—and had then a larger cooling surface in proportion to the volume of steam used, one would have expected some economy in favour of the gas-engine. For the moment, however, he would assume that both types of engine required the same proportionate increase of fuel, compared with that required per HP. under full-load. Broadly, then, his case was this: a gas-engine worked with generator-gas was now guaranteed to consume about 1 lb. per I.HP. per hour under full-load; whereas a non-condensing engine, such as was generally used in an electric-lighting station, required not less than 2 lbs., so that, under full-load, the saving with generator-gas should be about 50 per cent. Then, under a light load, he contended that the saving should be in the same proportion; and, in addition to this, there was the greatly reduced stand-by loss. Another way of looking at the question was,—as four volumes of generator-gas would develop the same power as one volume of ordinary town-gas, it was only necessary to multiply the average quantity of gas consumed per unit at Dessau, to obtain roundly the quantity of generator-gas required to do the same work, and to this should be added the stand-by loss in the generator. The average consumption of town-gas at Dessau was 40·8 cubic feet per unit generated, and that, multiplied by four, gave 163·2 cubic feet of generator-gas, which he knew from experience represented about $2\frac{1}{4}$ lbs. of fuel. The stand-by loss of the generator at Openshaw, which was about the size of that which would be required at Dessau, had been shown to vary between 4 lbs. and $7\frac{1}{2}$ lbs. per hour, which, on an average output of 355 units, would be but a mere fraction per unit generated. So it might be assumed that, in such a station as the one at Dessau, the average total fuel-consumption would be between $2\frac{1}{4}$ lbs. and

2½ lbs. per unit generated. In conclusion, he would venture to make two suggestions: one was that Professor Kennedy, or someone equally competent, should conduct a seven- or fourteen-day trial at Morecambe, under any reasonable working-conditions consistent with the public lighting not being interfered with. There were three engines and two generators, so that the question of light load could be well tried. On condition that the results were published, the engineers, Messrs. Andrews and Preece, had authorized him to offer the station for such a trial, and on his own part he would render any assistance he could. His other proposal was that a competitive trial should be made between steam- and gas-power, on the scale of about 100 HP., under all the varying conditions required in an electric-lighting station. If Professor Kennedy would conduct the trials, and publish the results for the benefit of all concerned, Mr. Dowson would provide the gas-plant required. He had not yet spoken to any one on the subject, but he thought it probable that one or more gas-engines would be lent; and, as to the dynamos and other apparatus required, there should not be much difficulty. It would then only remain to find a suitable steam-engine and boiler, and among the numerous advocates of steam there should be some one who would lend what was required. He feared that it would not be possible to place the steam-boiler on a weighing-machine, but it could be arranged to place the generator on one; and then, with frequent readings, there could be at all times and under every conceivable variation of load, an exact record of the conversion of the heat-energy of the fuel into electricity. That seemed to him to be the most practical way of dealing with the points at issue, and he felt also that, to some extent, the shortcomings of his Paper might by that means be met. Mr. Dowson.

Correspondence.

Mr. Santo Crimp supplied some facts relating to stand-by loss in boiler-furnaces. At three pumping-stations belonging to the London County Council storm-water alone was pumped and, consequently, the engines were generally at rest—sometimes for periods of time extending over several weeks—whilst steam had to be kept in the boilers in order to provide against any sudden down-pour of rain. The fuel consumed under those conditions was indicated in the following Table:— Mr. Crimp.

Mr. Crimp.

Station.	Boiler used.	Steam-Pressures.		Grate area.	Welsh Steam Coal Consumed per Superficial Foot.	
		Stand-by.	Working.		Stand-by.	Working.
No.	Feet.			Sq. Feet.	Lbs.	Lbs.
1	Cornish, 22 × 6	60	60	16·5	1·4	17·0
2	G.W.R. locomotive	40	100	16·0	0·84	62·5
3	,, ,,	60	110	16 0	1·00	66·5

In a new station for dealing with flood-water, lately completed, gas-engines had been introduced; and they were, undoubtedly, the best engines for the class of work under consideration.

Mr. Delamare.

Mr. E. Delamare Debouteville observed that the Author had ascribed the entire honour of the application of the gas-generator to gas-engines to Messrs. Crossley, whereas Mr. Debouteville had taken a large part in it. As early as 1884, in conjunction with Mr. Malandin, he had conducted trials of a gas-engine supplied from a Dowson generator, at their works at Fontaine le Bourg. In 1887 they had exhibited a 20-HP. motor working with Dowson gas at the Havre Exhibition. In 1888 they had completely solved the difficult problem of starting large motors, so that single cylinder engines of 50-HP. or 100-HP. could be constructed.[1] It had been mentioned by the Author that their 100-HP. motor worked with Dowson gas had only yielded 75 HP., and that the mechanical loss had been 35 HP. That was true; but the date of that early trial should have been given. It was the first time they had built such a large single-cylinder engine, and, in spite of their special experience of gas-motors, they could not be expected to have acquired for this particular case the knowledge necessary to ensure complete success. Since that time great progress had been made, and it had been ascertained that the indifferent working of that large engine was due to the weight of its moving parts, and to details of construction which were subsequently rectified. The 100-HP. motor had been installed in a cotton-spinning mill with 7,000 shuttles, and the results of three months' work with it were as follows:—

Daily work, 14 hours with full load.

Daily fuel consumption (including stoppage at night), 650 kilograms.

On the 23rd page the Author had said that up to the present

[1] Proceedings Inst. Mech. Eng., 1889, pp. 500 *et seq.*]

time no makers had thought it worth while to make special engines for generator-gas. That was a mistake, as, in 1892, Messrs. Delamare Debouteville and Co. had built a series of engines specially designed to work with generator-gas. Mr. Delamare.

The Gasmotoren-Fabrik Deutz, of Cologne stated that, from the first introduction of electric-lighting more than 10 years ago, they had endeavoured to adapt their engines to its requirements. They had constructed for this purpose double-cylinder engines which worked with great regularity, an explosion occurring at every revolution of the crank-shaft, and the governing of the engine being effected by a self-acting motion which introduced strong or weak charges into the cylinders, according to the power required. Subsequently, single-cylinder engines were also employed for driving dynamos. In order to obtain the necessary degree of regularity, the speed of these engines was increased, and they were provided with heavy fly-wheels. Besides this, their mode of governing was altered. Instead of being governed by missing charges, as hitherto, they were governed in the same manner as the double-cylinder engines. The dynamos were at first generally driven by belting, but later they were directly connected with the crank-shaft of double-cylinder or single-cylinder engines. At the present time, single-cylinder engines were generally used in connection with small installations for electric lighting. The Gasmotoren-Fabrik Deutz.

In 1881 the first large gas-engine was built by them for the sugar mills of Messrs. Pfeifer and Langen, of Elsdorf. This was a double-cylinder engine of 75 brake HP., which, after twelve years' work, remained in perfect working order, running day and night continually. About the same time a compound gas-engine of the same power was supplied to the same firm, provided with two small cylinders and one large cylinder, the latter only serving to continue the expansion of the exhaust gases from the two working cylinders alternately. They had built many large engines for electric-lighting purposes. A four-cylinder gas-engine of 150 brake HP., driving a dynamo directly coupled to the crank-shaft, was exhibited by them at the International Exhibition held at Cologne in 1889. This engine, during the four months which the Exhibition lasted, supplied the power for all the incandescent lamps and arc-lights without the help of accumulators.

They had for some years been building their own apparatus for the production of generator-gas. The gas thus produced did not differ from Dowson gas, though the apparatus was differently arranged. On the Deutz gas-plant, the gas from the hydraulic box did not pass to the condenser, but was conveyed to one or several

The Gasmotoren-Fabrik Deutz.

coke-scrubbers to be cooled and cleansed by water-jets; and, instead of a sawdust scrubber, a washer was employed, through which the gas passed previously to entering the gas-holder. The washer had proved to be more effective than a sawdust scrubber for cleansing the gas. There was, moreover, the objection against the latter that the sawdust, becoming damp in the course of time, clogged and obstructed the passage of the gas. All the parts of the apparatus were so constructed that at any time any one of them could be removed for inspection and cleansing. By a suitable arrangement of gas-cocks, the washer, scrubber, and generator might be shut off from the gas-holder, so that an escape of gas from the latter could not occur whilst they were being cleaned. With due regard to the poisonous nature of the gas and in accordance with the police regulations of Germany, all the parts of the apparatus were executed with the greatest care, especial pains being taken to ensure perfectly tight joints; the pipes, wherever possible, being made of cast-iron with faced flanges, and the pipe-joints made with packing-rings, so that escape of the gas was impossible.

The "Otto" engine had the advantage that, for all kinds of gas, the same design of engine and the same dimensions of the parts, with trifling modifications, could be used. There was no difficulty, in spite of the presence of the products of combustion, in conveying to the cylinders a sufficiently strong charge of generator-gas, provided that the passages of admission were large enough; exact ignition was easily obtained by graduating the compression accordingly. All their engines of approximately the same power were of the same size, whether intended for coal-gas or generator-gas.

With regard to the working expenses of electric light produced by means of gas-engines, it was remarkable that, in small installations for electric-lighting, the amount of light produced by directly burning gas, would be obtained electrically by means of a gas-engine with only one-half the quantity of gas. The following trial, made at an electric-lighting station at Bremen with a 12-HP. double-cylinder engine erected in 1891, would illustrate that statement. During the trial the engine served 145 glow-lamps and 2 arc-lamps of 6 amperes each. The readings of the meters gave:

70·5 Amperes
110·5 Volts } . . . . . 7790·25 Watts.

The consumption of gas was 10·2 cubic metres per hour. Assuming the two arc-lamps to be equal to twelve glow-lamps each

glow-lamp consumed 65 litres, or 2·3 cubic feet of Bremen coal-gas, and 1 kilowatt required 1·317 cubic metre, or 47 cubic feet of gas. With regard to the cost of electric light produced by means of generator-gas engines, they could not offer exact statements from actual observation, but could only state that the users of such engines were highly satisfied with their economical working. The Gasmotoren-Fabrik Deutz.

Mr. Thomas Holgate observed that some advantage was secured by the use of an engine worked by gas—generated by the interaction of air, steam, and carbon—rather than by a steam-engine. The capital outlay and the yearly charge for the former were less than for the latter. Against those important considerations, the objection had been raised that gas-power required more attention than steam-power, owing to the ports of the valves and the cylinders requiring to be cleaned daily, and to the time occupied in starting the engines, and to other causes. The larger engines now being made, fitted with self-starting appliances, should overcome some of these objections. Mr. Holgate had had occasion during the past year to compare the estimated cost of an installation of electric-generating plant driven (*a*) by steam-power, and (*b*) by Mr. Holgate.

Estimated Cost of an Electric-Generating-Plant for 10,000 (Running) 16-c.p. Lamps. Electromotive Force, 120 Volts.

Area available at central-station 880 square yards.

(*a*) Steam-Power.	£.	£.	(*b*) Gas-Power.	£.	£.
Five 160 HP. boilers.	3,365		Dowson gas-plant to provide 1,160 I.HP.	2,000	
Five mechanical stokers	720				
		4,085			2,000
Four 250 I.HP. compound engines . .	7,000		Seven 122 B.HP. gas-engines . .		
Two 80 I.HP. compound engines . .	1,150		Two 61 B.HP. gas-engines . . .	equal to 1,160 I.HP.	
Pumps, valves, pipes, feed-heaters, &c. .	2,030		Two 34 B.HP. gas-engines . . .		
		10,180			9,012
Four dynamos, each 150 kilowatts . .	3,200		Seven dynamos, each 81·6 kilowatts . .		
Two dynamos, each 50 kilowatts . . .	800		Two dynamos, each 40·8 kilowatts . .	5,191	
			Two dynamos, each 21·6 kilowatts . .		
Six sets of cotton driving-ropes . . .	100	4,100	Leather belting . .	304	5,495
For 700 kilowatts	Total	18,365	For 696 kilowatts	Total	16,507

Mr. Holgate. gas-power. In the result, the gas-power scheme appeared at a disadvantage owing to the smallness of its units; and, consequently, the greater number of dynamos required. It would be seen, however, that even then, the cost for gas-power was slightly lower than for steam-power, though the floor-space required was rather more.

Two methods of using gas-power had been suggested by the Author to gas-engineers, either at the works, or in generating-stations near the centre of the lighting-area. To the resources mentioned in the Paper as available at gas-works might be added others favourable to the use of either gas or steam. The most important of these were: (1) A great deal of heat from retort settings usually passed up the chimneys not utilized. This might be used for generating all the steam required for Dowson gas-plant, or to generate steam for steam-driven dynamos. (2) A large quantity of breeze from coke, which was at present almost unsaleable, might be used to raise steam, by employing forced draught under the boiler-grate. (3) Red-hot coke might be drawn straight from the retorts into the Dowson generator. Thus it appeared that electricity might be conveniently generated at gas-works, either by steam- or gas-power, or by a combination of the two. The elasticity so much needed in a steam-plant might be obtained to some extent from the waste heat from the retort-settings. In a gas-power plant that elasticity was found in the Dowson generator and in the coal-gas stored in the gas-holders.

Mr. Lane. Mr. Denny Lane pointed out that the greatest difficulty with regard to electric lighting had arisen from the distribution of the current, because if the electro-motive force were high, it caused danger and increased the difficulty of insulation, and, if low, it involved great expense in the conductors. The increase in this outlay on conductors had been calculated to augment proportionally to the square of the distance, and had led to the employment of transformers of the current from high to low tension, all of which caused a heavy loss. Moreover, the alternate-current transformers had not yet been employed to any extent for the transmission of power, which would tend, by making the load-factor more uniform, to reduce the average cost of current. The solution of the difficulty could be best effected by distributing the sources of electrical supply, and by substituting several smaller generating-stations for each larger one. With ordinary town-gas of 16 candle-power, 3,000 HP. could be sent a distance of 1 mile

for an expenditure of 1 HP.[1] an economy of distribution far exceeding that possessed by any other system, either hydraulic, pneumatic, or electric, being only $\frac{1}{30}$ per cent. of the power conveyed. With water-gas the amount of loss would be about double, while with generator gases such as the Author mentions, the loss would probably not much exceed $\frac{1}{4}$ per cent. If gas-pipes were laid properly, so as to avoid leakage, an increase in the initial force would produce a larger delivery at a very small increase of cost. If the delivery were doubled the initial pressure should be quadrupled, and the cost of conveyance would still be only $\frac{1}{3,000} \times 4 = \frac{1}{750}$ HP. for town-gas, and for generator-gas not much more than $\frac{1}{100}$ HP. per mile. A gas-engine, once started, required no attendance for hours, so that the cost of labour was extremely small, and, as far as the engine was concerned, one man might attend to the gas-engines distributed over several generating-stations; especially if storage batteries were employed for the low consumption by day. The wear and tear of modern gas-engines was trifling, and they worked for many years without any outlay on that account, when they might perhaps require an outlay of 3 or 5 per cent. of their cost to make them equal to new. They were also absolutely free from danger, excepting that which accompanied all machines running at high velocity, and this could be easily provided against. With respect to the cost of mains, taking the cost of conductors laid on the low-pressure culvert system at £5,500 per mile, for the conveyance of 1,080 amperes, and assuming an electromotive force of 110 volts, the power would be 158 HP. It would therefore require two pairs of these conductors to convey 300 HP., whilst a 6-inch main, with ordinary gas, would convey sufficient gas for that power at 4 inches pressure, and, at 16 inches, would deliver as much as four pairs of such conductors. The 6-inch main would cost from £500 to £600 per mile, whilst two pairs of low-pressure conductors would cost £11,000, and four pairs would involve an expenditure of £22,000 per mile. That was supposing that there was no loss of electric energy in transmission, whereas it was well known that the loss from heating in the conductor was very great. Assuming that a gas-main was laid specially for electrical service without any service-pipes taken off for other purposes, and charging the whole outlay to this department, with a properly laid main, the loss in transmission would be inappreciable. The foregoing comparison referred to ordinary London gas. With Dowson or other generator-gas of low heating power, the area of the mains should be larger

Mr. Lane.

[1] *Electrician*, 9 Oct., 1891.

Mr. Lane. in the inverse ratio of the calorific capacity of the gas employed. The performance of gas-engines supplying electric light might be summarized thus :—

A good gas-engine should give 1 brake HP. with	30	cubic feet of gas per HP.
A good dynamo should convert 90 per cent. of power into electricity . .	33·3	„ „
One kilowatt (=1⅓ HP.) should be produced for	44·4	„ „

Allowing 10 per cent. loss in distribution, it would therefore appear that one unit could be generated and distributed for about 50 cubic feet of 16-candle-power gas.

Dr. Monaco. Dr. Cesare Monaco contributed the following particulars of experiments on Dowson gas. The experiments were made on January 9th and 10th, 1890, with a Dowson apparatus connected with a 40-brake-HP. Otto gas-engine, erected in a mill at Canale, in Piedmont. The installation for the production of the Dowson gas comprised the boiler, the generator—with a capacity of about 4,800 cubic feet per hour—the coke scrubber, and a small gas-holder. During the progress of the experiments he analysed the products of combustion, and took with the greatest care various samples of gas from the gas-holder, also of anthracite, which he afterwards analysed at Turin, at the Laboratory of Chemical Technology of the Royal Italian Industrial Museum. Orsat's modified apparatus was used for analysing the products of combustion, and Fischer's apparatus for the Dowson gas. The results of those analyses, made with scrupulous precision, were :—

Average Composition of Dowson Gas (Canale, Piedmont) at 32° F. and 14·22 lbs. Pressure per Square Inch.

—	Per cent.	Weight in lbs. per 1,000 cubic feet.
Carbonic acid	0·0840	10·057
Oxygen	0·0090	0·784
Hydrogen	0·1647	0·897
Carbonic oxide (CO)	0·2750	20·948
Nitrogen	0·4673	35·595
Total	1·0000	68·281

Comparing that result with other analyses of Dowson gas, it would be seen that the sample at Canale was of fairly good average quality.

The specific weight and volume of the above samples at 32° F. and 14·22 lbs. pressure per square inch were respectively 0·068 lb. and 0·918 lb. per cubic foot. The composition by weight of each element was:— Dr. Monaco.

Carbonic acid	0·1473
Oxygen	0·0115
Hydrogen	0·0132
Carbonic oxide	0·3067
Nitrogen	0·5213
	1·0000

The average composition of the products of combustion was:—

Carbonic acid	9·08
Oxygen	15·04
Carbonic oxide	15·69
Nitrogen	60·19
	100·00

From the preceding analyses of the products of combustion, it would be seen that the process was thoroughly effective. The chemical composition of the Dowson gas gave the following data:—

Theoretical volume of air required for the complete combustion of 1 cubic foot of gas	= 1 cubic foot
Volume of air actually admitted	= 1·2 „
Specific heat, at constant pressure, of the products of combustion of 1 cubic foot of gas and 1·2 cubic foot of air	= 0·247
Specific heat, at constant volume, of the same	= 0·177
Ratio of specific heat at constant pressure to that at constant volume	1·40

Composition of Anthracite.

Water	0·0170
Coke	0·9290
Ashes	0·0389
Sulphur	0·0083
	0·9932

To produce the weight of 10·057 lbs. of carbonic acid in 1,000 cubic feet of gas, the weight of carbon required was

$$\frac{3}{11} \times 10{\cdot}057 = 2{\cdot}743 \text{ lbs.};$$

Dr. Monaco. and for the weight of 20·948 lbs. of carbonic oxide, the weight of carbon was

$$\frac{3}{7} \times 20{\cdot}948 = 8{\cdot}978 \text{ lbs.}$$

The total weight of carbon in 1,000 cubic feet of gas was therefore 11·721 lbs. If the whole of this carbon were brought into the gaseous state, the product of 1 lb. of anthracite would be

$$\frac{0{\cdot}929 \times 28{\cdot}5 \times 35{\cdot}1}{11{\cdot}721} = 79{\cdot}2 \text{ cubic feet.}$$

This maximum theoretical result was practically unattainable, as an appreciable quantity of carbon was converted mechanically from the gaseous to the solid state. The volume of gas produced being, therefore, not capable of direct determination, it was assumed (hypothetically) that the carbon thus mechanically eliminated was equivalent to 10 per cent. of the whole, so that the amount of carbon transferred to the gaseous state from 1 lb. of anthracite would be 71·3 cubic feet. Taking the calorific power of hydrogen at 29,060 calories, that of carbonic oxide at 2,400 calories, and that of ordinary illuminating-gas at 5,000 calories, the equivalent value of Dowson gas was 1,216, *i.e.*, about one-fourth part of the calorific power of coal-gas. A similar result, viz., 1,313 calories, had been given by Schilling. The cost of producing Dowson gas being 4*d.* per 1,000 cubic feet, whilst coal gas at Turin cost 3*s.* 9*d.* per 1,000 cubic feet, the value of Dowson gas for an equivalent calorific power, was thus four times 4*d.*, or 1*s.* 4*d.*, *i.e.* about one-third the cost of coal-gas.

Mr. Perry. Mr. James Perry had not long been connected with the management of an electric central-station when he was struck with the value of gas as a distributor of power. He competed with a gas company both in lighting and power, and in order to compete with them in power, had to sell electricity for motive purposes at one-half what was charged for illumination. That probably did not quite apply to small powers, where the handiness and simplicity of the motor formed a strong recommendation. For example, if (to satisfy gas-consumers) it were agreed that electricity at 3*d.* per unit was equivalent to gas at 2*s.* 6*d.* per 1,000 cubic feet for illuminating purposes, then it had to be sold at 1½*d.* to be equivalent for power purposes; and if gas companies took to making cheap motor-gas, they might, except for small powers, continue for a long time to be able to under-sell electric companies in power, and they might have a monopoly of heating. He had been abused for saying

that illuminating-gas was on its death-bed; but, as a means of distributing power obtained from coal, gas had no dangerous rival. Mr. Perry.

Dr. Du Riche Preller said with regard to the Author's ideal electric-lighting central-station of 500 HP., or 400 kilowatts, he might refer to a recent case in point within his experience. In 1891 when he was at Zurich, designs were being prepared for the corporation electric-lighting installation of 1,200 HP., or about 800 kilowatts, which had since been carried out. To meet the contingency of extraordinary demand or extension, a reserve of 600 HP. had to be provided, and it was first proposed to use gas-engines, driven either by corporation- or by Dowson gas, for which there was, *primâ facie*, every inducement, seeing that in Switzerland the cost of steam power was enhanced by the high cost of imported fuel. Nevertheless, the corporation decided to erect two 300-HP. steam-engines, for they arrived at the conclusion that even the largest gas-engines so far made were not adapted for large central-stations, because they do not work economically except under full load, and also because their efficiency in actual practice was an uncertain factor compared with that of steam-engines. For smaller installations, on the other hand, either with town-gas or Dowson gas, gas-engines offered in many cases considerable advantages. Moreover, in all cases, the use of town-gas, Dowson gas and petroleum must be governed very much by local conditions. Where town-gas cost 3*s.* to 3*s.* 6*d.* per 1,000 cubic feet, as it did at Basle and Turin, it would be preferable to Dowson gas; where it ran up to 5*s.* and 6*s.*, as at Zurich, the small petroleum-motor would be preferred to either; while for small municipal electric-lighting stations, the favourite theory of the local authorities, both in England and abroad, of compensating the reduced consumption of town-gas by using it for driving dynamos, was necessarily opposed to the use of Dowson gas. As regarded petroleum-engines, the import duty levied in Italy on petroleum, equal to three times the prime cost of the oil, absolutely prohibited the use of those motors for the present in that country. As regarded the Author's contention that, in his ideal central-station, the gas-engine in connection with the generator would remove or mitigate the loss of power due to the variable load-factor in dynamo-driving steam-engines, it should be borne in mind that that loss of power would always be unavoidable, so long as electricity, acting only as an agent for distributing energy, had to be generated by a primary motor and did not itself become the primary power. It followed that the remedy for the waste of steam-power and electrical energy must not be sought in the Dowson generator and in gas-engines; Dr. Preller.

Dr. Preller. and it could only be compensated and avoided as far as possible, by means of accumulators. Another point to which he would call attention was that of gas-engines compared with high-speed steam-engines for central stations of electric railways. There the case was of course very different, because it was not safe to exceed a potential of 500 to 700 volts; and the efficiency of the primary motor, in respect, not of the dynamo, but of the motors of the motor-car or of the electric locomotive, formed an important determining factor. For instance, on the Florence and Fiesole Electric Railway,[1] with which he had been concerned, power was generated by 3 high-speed vertical compound steam-engines of 90 HP. each, which made 225 revolutions per minute, and drove 3 Edison dynamos making 900 revolutions per minute, giving 90 per cent. efficiency in respect of the dynamos. The line had continuous steep gradients of 5 in 100 and 8 in 100, with sharp curves, and the electric energy required for the ordinary 20-minute service was about 3,500 watts, or 45 HP.; which, having regard to greater friction of gear on the steep grades, and the additional energy required for starting, corresponded to about 75 HP. to be supplied by the central-station, equal to an efficiency of 60 per cent. The consumption of fuel per HP. in respect of the car-motor was 5 lbs. per HP. per hour, and it was obvious that on such a line, even if it were level, high-speed steam-engines would not work economically unless the service were at least a 10-minute instead of a 20-minute one. For such moderate-sized installations, gas-engines were more advantageous than steam-engines. At Kiew, in Russia, the power for the electric-tramway was generated by two 80-HP. Otto engines. The last point he would mention referred to motors for electric lighthouses. Within the last few years he had investigated the electric lighthouse of Tino, situated on a small island outside the Bay of Spezia, in the Mediterranean. The installation, which dated from 1885,[2] was perfect, except in one respect, that the De Meritens dynamos were driven by two troublesome Brown hot-air engines of 33 HP., which at first only gave 9 (effective) HP., and, after a few years, not even half of that; so that they could not produce the 4,000 watts requisite for the electric light. The Lighthouse Department therefore resolved in 1891 to introduce a compound 6-HP. steam-engine, although there was no water on the island. In this case, the use of steam was a great mistake, and a petroleum-motor,

[1] Minutes of Proceedings Inst. C.E., vol. cvi.

[2] *Ibid.*, vol. lxxxvii.

with the tank placed at some distance from the lighthouse and connected with it by an underground feed-pipe, would have been in every respect more economical. Dr. Preller.

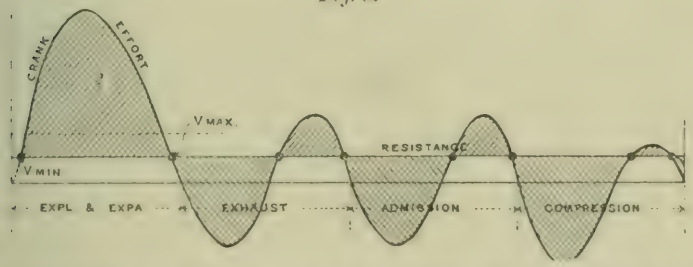
Mr. E. C. De Segundo observed that the Author had arrived at an economy of 50 per cent. by burning the gas in a gas-engine to produce electric light, as against using gas-burners, and that assertion was repeated as a result arrived at by a Continental gas company, from trials extending over many years. Nothing, however, had been said about the manner in which the trials were carried out, nor of the methods employed in making the various measurements, nor of their kind, nor of the persons who conducted them. That economy of 50 per cent. contained the pith of the whole argument, which the Author had founded upon a comparison of gas and electricity on a basis of light for light, which was unfair. It was stated in the Paper: "If 47 cubic feet of gas are allowed to produce 1 kilowatt, and if 55 watts give a light of 16-candle power, one of these lights will require only 2·6 cubic feet per hour; whereas a standard Argand burner requires 5 cubic feet per hour." That comparison was unjust, because there was no lamp in England which would yield 16-candle power for an expenditure of electric energy at the rate of 55 watts; because 47 cubic feet of gas per kilowatt-hour would not appear (on an examination of Appendix K) to be a fairly representative performance for a gas-engine such as would be used in central-station work; and because the average gas-burner was not an Argand. It would have been fairer to compare the performance of an arc-lamp with that of an Argand burner. Respecting electric light generated by gas-power with light produced by gas burnt in burners, it should be borne in mind that gas and electricity were not comparable; and whereas the nature of electricity would not be altered, being a force over whose physical characteristics absolutely no control could be exercised, gas for illuminating purposes presented an unlimited field for improvement in the composition of the substance itself. Thus, whilst only the means of applying electricity to various objects could be rendered more efficient, both gas and the methods of using it might be improved upon. Instituting a comparison on the basis of daily practical performance, he would adopt the Author's figure of 47 cubic feet of gas per kilowatt. In assuming the performance of a 16-candle-power glow-lamp, he would base his calculation on experiments made over 1,000 hours with several lamps, and would take the average of those measurements. This amounted to $3\frac{3}{4}$ watts per candle. He had, therefore, little hesitation in Mr. Segundo.

Mr. Segundo. accepting 4 watts per candle as very near to the truth. For 47 cubic feet burned in a gas-engine, $\frac{1,000}{4} = 250$ candle-power hours would be obtained, which is at the rate of $\frac{1,000}{47} \times 250$ candle-power hours per thousand cubic feet of gas. The results of many experiments with ordinary burners, was that 5 cubic feet of gas did not, on the average, yield more than $12\frac{1}{2}$ candle-power. At that rate, 1,000 cubic feet of gas burnt through burners could yield only 2,500 candle-power hours. There should be, therefore, on the score of light for light, an advantage of $\frac{5,320 - 2,500}{2,500} = 102{\cdot}8$ per cent. in producing electric light by gas in a gas-engine over burning it in burners. Turning to a comparison of the two systems, on the basis of what might be expected in the near future, the Author had stated that a performance of 22 cubic feet, or even 17·6 cubic feet, per brake HP. in a 120 HP. gas-engine, might be expected, and so about 30 cubic feet per kilowatt at the dynamo-terminals. Assuming 2 watts per candle-power as the limit of efficiency possible in incandescent lamps, for 1,000 cubic feet of gas burned in a gas-engine, $\frac{500,000}{30} = 16,670$ c.p. hours might be expected. But gas-engineers were not going to be idle in the meantime. At the present moment, if people chose to spend on their gas-burners as much as they did on electric lamps and renewals, they could obtain about 6,000 c.p. hours for 1,000 cubic feet of gas. Gas-burners would possibly be further improved; and, in one case which had come under Mr. De Segundo's observation, the burner yielded a rate of 15,000 c.p. hours per 1,000 cubic feet of gas. There appeared, further, to be good ground for believing that an oil-gas, which might now be said to have passed the experimental stage, would yield 78 c.p. hours per 5 cubic feet of gas in an ordinary gas-burner of good construction. Taking gas-engine power at its best for electric-lighting purposes, it was quite possible for gas-engineers to beat it when burning gas through burners. The substitution of gas for steam in central-stations had been suggested in the Paper on the strength of results obtained under conditions which did not bear even a distant similarity to those obtaining at such stations. The reliability of a gas-engine of large power had not yet been demonstrated, and, from the Author's results, it was not clear that a continued efficiency of 80 per cent. could be reckoned on. Moreover, there could be no doubt that high-speed

coupled direct-driving was essential for central-station work in large towns where land was dear. Was there as yet anything known of a gas-engine whose performance approached that of a Willans engine in any particular? It was difficult to see where the economy of gas-power would be effected; and more difficult still to gather anything from the results given in the Paper, which would throw any light upon the question. Mr. Segundo.

Mr. Archibald Sharp exhibited a diagram, *Fig. 9*, showing the curve of crank-pin effort in a gas-engine with the Otto cycle, allowance having been made for the acceleration and retardation of the reciprocating parts. When driving a dynamo, the effort required to overcome the resistance was practically represented by a straight line parallel to the axis of the diagram. The abscissae represented distances passed over by the crank-pin, and the ordinates the corresponding effort. When the effort was greater than Mr. Sharp.

Fig. 9.



the resistance, the speed of the shaft increased, and would attain a maximum value when the effort and resistance were equal. When the effort was less than the resistance, the speed of the shaft diminished, and reached a minimum when the effort and resistance were again equal. The excess of energy exerted on the crank-pin above that expended in overcoming resistance, was stored by the fly-wheel.

If E denoted the average amount of energy stored by the fly-wheel, V, the average velocity of the fly-wheel rim, d E and d V were the differences between the greatest and least of these quantities respectively, and W the weight of the fly-wheel.

$$\mathrm{E} = \frac{\mathrm{W}\,\mathrm{V}^2}{2\,g} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (i)$$

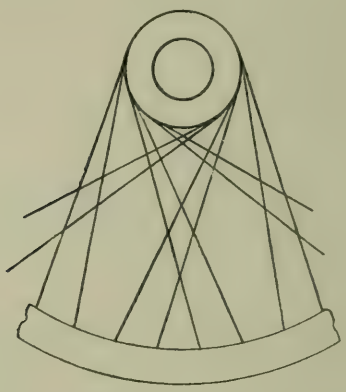
Differentiating, $$d\,\mathrm{E} = \frac{\mathrm{W}\,\mathrm{V}}{g}\,d\,\mathrm{V},$$

therefore, $$\frac{d\,\mathrm{V}}{\mathrm{V}} = \frac{g}{\mathrm{W}\,\mathrm{V}^2}\,d\,\mathrm{E} \quad . \quad . \quad . \quad . \quad (ii)$$

Mr. Sharp. $\frac{d\,V}{V}$ was the fluctuation of velocity, and, in engines for driving dynamos, should be reduced as far as possible. An inspection of equation (*ii*) showed that there were three methods of diminishing this fluctuation of velocity.

(1.) Diminish $d\,E$, the excess of energy. This could be done by putting two or more engines on the same shaft, and, in the case of double-acting steam-engines, a comparatively constant turning effort on the shaft was obtained by that means. But in the Otto cycle gas-engine, the same advantage was not obtained. If two Otto gas-engines were coupled on the same shaft, the area —though not the form—of the effort curve during the explosion and expansion stroke remained the same. The mean resistance,

Fig. 10.



represented by the dotted line in *Fig. 9*, was doubled. The excess of energy, represented by the shaded area above the dotted line, was still about three-quarters of its original value, and the reduction of fluctuation of speed was correspondingly small.

(2.) Increase W. Equation (*ii*) showed that the fluctuation of velocity was inversely proportional to the weight of the fly-wheel.

(3.) Increase V. The equation showed that the fluctuation of velocity was proportional to the inverse square of the average velocity of the fly-wheel rim.

Fig. 10 showed the construction of a fly-wheel invented by Mr. Sharp, to run safely at very high speeds. The rim and the nave were cast-iron and the spokes were mild steel. Each pair of spokes was formed from one piece of rod bent round the nave with an arc of contact with it of $\frac{1}{3}$ turn to $\frac{1}{2}$ turn. The ends of the rod were fastened to the rim by nuts. There was no attach-

ment of the spokes to the nave, the friction due to the initial tension of the spokes being sufficient to prevent slipping. Bicycle wheels built on this system were already in the market. The rim when at rest was subject to circumferential compression. By suitably choosing the initial tension in the spokes, the stress in the rim when rotating might be either compressive, neutral, or tensile. Mr. Sharp.

Dr. Aimé Witz, of Lille, drew attention to the fact that he had last year demonstrated that it was possible to effect great economy by burning town-gas in the cylinder of an engine instead of in a gas-burner.[1] This year he had proved, in a spinning-mill at Lille, that this economy might attain 45 per cent. A consumption of 40 cubic metres of gas per hour had been reduced to about 22 cubic metres, which only cost 15 centimes per cubic metre instead of 21 centimes, so that the pecuniary saving exceeded 60 per cent. He entirely concurred in the Author's second and third propositions; and his experiments at Rouen, alluded to in the Paper, were conclusive in this respect. The employment of generators would not long delay the attainment of far superior results. One HP. per hour would soon be obtained for 450 grams of coal. Unfortunately, the generator would only deal with anthracite and coke—flaming coal could hardly be utilized; but it was essential that every kind and form of coal, even dust, should be available. When that was realized, the generator would replace the steam-boiler almost universally. Dr. Witz.

Mr. J. E. Dowson, in reply to the remarks of Mr. Delamare Debouteville, observed that it was beyond doubt that Messrs. Crossley were the first to use generator-gas in gas-engines; they were followed by the Gasmotoren-Fabrik of Deutz, and afterwards by Mr. Powell of Rouen. In all cases the Dowson gas-plant was used. It was Mr. Powell who exhibited a 20-brake HP. engine, when the Author showed a gas-plant at the Havre Exhibition, and a gold medal was awarded to them jointly. Other gas-engine makers adopted Dowson-gas at a later date, and those who did so were referred to on pages 15 to 18 of the Paper. While admitting that credit was due to Mr. Delamare and his co-patentee for their long struggle in connection with gas-power, they could not claim to have done anything with generator-gas before 1884, and it was not till 1886 that they were able to try a 25-HP. engine with it. On the other hand, Messrs. Crossley experimented with Dowson-gas as early as 1879; and, since 1882 they had used it exclusively for the power at their works. It was hardly a fact that large gas-engines were not constructed before Mr. Dowson.

[1] Revue Générale des Sciences. Tome, 1892. Comptes Rendus. Tome cxiv. 1892.

Mr. Dowson. the Delamare and Malandin starting-arrangement was introduced. Several large engines were made before then, and no other maker before or since had ever used the rather primitive starting-gear of Messrs. Delamare and Malandin. With regard to the so-called 100-HP. engine, a trial of it was made by Professor Witz in September 1890, as mentioned on page 15 of the Paper, and it was then found that owing to excessive friction the maximum brake HP. was only about 75. The engine had since been altered, and was now working at the cotton mill belonging to a relative of Mr. Delamare; but the power actually developed was not given, so that the fuel-consumption per HP. per hour could not be estimated. As to the remarks of the Gasmotoren-Fabrik on the subject of the Otto engine, the Author could readily understand that from a maker's point of view it was preferable to keep the same design of engine for all kinds of gas. Under the best conditions it was possible to introduce enough generator-gas in the cylinder to obtain the same power as with town-gas of low candle-power; but the various disadvantages described in the Paper of diluting the generator-gas with products of combustion remained. This was admitted by Dr. Otto in the patent specification quoted by the Author on page 45. He observed that Mr. Holgate was under the impression that the valves and cylinders of gas-engines should be cleaned daily; but he desired to say that when ordinary town-gas was used, the valves need not be cleaned more than once a month and the cylinder once in three months, and that when generator-gas was used the valves should be cleaned once a fortnight, sometimes once a week, and the cylinder once a month. The statement of Dr. Preller as to what was proposed at Zurich in 1891 was probably correct, but at the present time it was seriously contemplated to have engines driven with Dowson-gas for 300 brake HP., and Mr. Dowson had prepared certain designs which were now under consideration. It was proposed to make the gas with coke from the Municipal Gas-Works, and this alone was considered advantageous. As regarded the cost of town-gas in Zurich, Lucerne, Neuchâtel, as well as in most other Swiss towns, it was usually 4*s.* to 4*s.* 6*d.* per 1,000 cubic feet. For some years Dowson-gas plant had been in use at Neuchâtel, Lucerne, Arlesheim near Basle, Sainte Croix, Birmensdorf near Zurich, Bercher and Gersau, and notwithstanding the high price of anthracite coal, the average cost of the quantity of Dowson gas equal to 1,000 cubic feet of the town-gas was 1*s.* 9*d.* If Mr. Segundo would consult the Paper of Mr. W. von Oechelhäuser referred to on page 5, he would find many interesting details concerning the working of the Dessau installation, and he need not doubt the

competency of those who made the observations, or of those who compiled the returns. Mr. Dowson adhered to his opinion that for a central station a consumption of about 47 cubic feet of town-gas in an engine was fully sufficient for one kilowatt-hour generated. At Morecambe the average of two weeks was about 40 cubic feet per kilowatt-hour delivered, including the loss in accumulators and mains. At Dessau the average of a whole month was under 41 cubic feet per kilowatt-hour generated. The light of a glow-lamp had been compared with that of an Argand burner, because it appeared to be more exact to compare the glow-lamp at its best with gas burnt in the recognised standard burner; if the comparison were made with batswing or other burners it would be so much the worse for the gas. With regard to Mr. Segundo's statement that it would have been fairer to compare an arc-lamp with an Argand burner, on page 6 of the Paper particulars were given of such a comparison made by the late Sir William Siemens. As to the current required per candle-power in glow-lamps, the common practice in England was to allow $3\frac{1}{2}$ to $3\frac{3}{4}$ watts; but on the Continent it was more usual to have lamps with less resistance, and to allow 3 to $3\frac{1}{4}$ watts. At Dessau the 16 candle-power lamps actually used took 55 watts each per hour. Mr. Dowson would remind Mr. Segundo that for practical purposes all were concerned with the applications of electricity and gas, and that the amount of serviceable light obtained with each, under the best known conditions, could only be compared. Electric lamps would doubtless be improved as well as gas-burners; but in the meantime what was actually available had to be considered. As to the statement that the results referred to in the Paper "were obtained under conditions which did not bear even a distant similarity to those obtained at central stations," Mr. Dowson would reply that even if all other results were set aside, the installations at Dessau, Schwabing and Morecambe were all doing central-station work and nothing else. Mr. Dowson.

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17 and 24 January, 1893.

HARRISON HAYTER, President,
in the Chair.

The discussion on the Paper by Mr. J. Emerson Dowson, upon "Gas-power for Electric Lighting," occupied these meetings. After the meeting of the 17th January, the President and Council held the first monthly reception of the Session.

[List of Models and Apparatus.

LIST OF MODELS AND APPARATUS

EXHIBITED AT THE MONTHLY RECEPTION, 17 JANUARY, 1893.

Exhibitor.	Objects.
J. E. H. Andrew & Co. . .	Model of sections of working parts of 100 HP. (indicated) "Stockport" gas-engine, with Otto cycle, and showing attachments of self-starter.
	Photograph of "Stockport" gas-engine.
British Gas-Engine & Engineering Company.	Model of Atkinson "Cycle" gas-engine.
	Photographs (2) of Atkinson gas-engine (new type).
Brush Electrical Engineering Company.	Commutators (9).
	Compound switch and fuse.
	Electric light brackets (2).
	Lightning-arrester.
	Simple and compound fuses (2).
	Switches (3).
	Transformer.
Dugald Clerk, Assoc. M. Inst. C.E.	Set of Lanchester's self-starting gear for a 16-HP. gas-engine.
Crossley Brothers & Co. .	Gas-engine (2 HP.) combined with "Crompton" dynamo.
Day & Co.	Gas-engine.
Dick, Kerr & Co.	Photograph of double-acting horizontal gas-engine.
Drake & Gorham . . .	Automatic regulating-switch.
	"Nevile" automatic accumulator-switch.
	"Tipper" switch.
Elliott Brothers . . .	Goold's pulley- and belting-calculator.
	Pollit's pipe-calculator or slide-rule.
Fielding & Platt . . .	Photograph of 30 HP. (nominal) gas-engine.
William Foster	Apparatus for testing lighting value of gas by different burners.
Fritsche & Pischon . . .	Photographs (5) of "Rad-Anker" dynamo.
E. R. Gabbett, M. Inst. C.E.	Model of rapid mixer.
Galloways	Model of "Galloway" steam-boiler.
H. Graham Harris, M. Inst. C.E.	Working model of "Day" gas-engine.
Hugo Junkers	Calorimeter.
Körting Brothers . . .	Photograph of "Körting" engine and dynamo coupled.
Manlove, Alliott & Co. .	"Ransom" cyclometer.
J. & O. G. Pierson . . .	Photograph of "Derrozier" dynamo coupled to high-speed gas-engine by "Raffard" elastic coupling.
A. Ransome & Co. . . .	Model of steam tree-feller.

Exhibitor.	Objects.
Archibald Sharp, Assoc. M. Inst. C.E.	"Sharp" tangent wheel for bicycles.
Siemens Brothers & Co. .	Gas-lamps (2) fitted with "Siemens" burners.
J. E. Spagnoletti & Crookes	Samples of electric lighting apparatus.
Tangyes (Limited) . . .	Photograph of 35-HP. (nominal) gas-engine.
Thames Iron Works & Shipbuilding Company.	Model of "Hone" grab.
Francis S. Thomas, Assoc. M. Inst. C.E.	Model of "Box" rail-joint.
Charles J. Wilson . . .	Apparatus for collecting exhaust gases.
	Apparatus for analysing exhaust gases.
Yarrow & Co.	Models of 1st- and 2nd-class torpedo-boats.
	Models of stern-wheel steamers "Mosquito" and "Herald."

31 January, 1893.

HARRISON HAYTER, President,
in the Chair.

(*Paper No. 2655.*)

"Smelting Processes for the Extraction of Silver and Gold from their Ores."

By Henry Francis Collins, A.R.S.M., Assoc. M. Inst. C.E.

In this Paper an attempt has been made to describe the best and most modern smelting-practice on the American Continent; for nowhere else is the extraction of silver and gold conducted on such a large scale and under such varied conditions. Most of the processes used are, in their general principles, well known. Many of them, indeed, date from remote antiquity, and nearly all have been at some period employed in various parts of Europe; especially in the Freiberg and Hartz districts of Germany, where almost all the known kinds of silver ores have been met with in greater or less quantity. The modifications and improvements in these processes, and in the mechanical arrangements by which they are applied in modern American practice, are the necessary outcome of local conditions; among which may be mentioned the following in particular:—1. The enormous size and richness of the bodies of ore occurring in the noted mineral districts of Leadville, Aspen, Butte, &c.; and the greater facilities for working them, compared with the narrow fissure-veins of Saxony and the Hartz. 2. The scarcity and high price of labour, especially of skilled labour.

When the vast deposits of lead-carbonate ores at Leadville were laid open in 1878, the surrounding country afforded no materials of construction other than timber, and no skilled labour except that of the miner, whilst the ores were not only abundant, but rich and exceedingly docile; so that a system of smelting which would treat large quantities of ore rapidly and without any great expense for labour, became at once an all-important requirement. This want led to the adoption of a simple type of water-

jacketed lead-furnace, from which has been gradually evolved the furnace now to be found at all the great lead-smelting establishments of the West, and described in the following pages. In the same way, the discoveries of copper ores at Butte, Montana, coupled with the high prices of labour and fuel, led to improvements being made in the old Swansea type of reverberatory furnace, increasing the size of the hearth, so as to allow larger charges to be put through in proportion to the consumption of fuel and labour. It may, indeed, be said, that all the improvements that have been effected in American metallurgical works, have had for their object either the direct saving of labour, or else the adoption of automatic appliances; with a view to ensure greater uniformity in the results, and thereby independence of specially-trained and experienced workmen, who are more difficult to procure and less reliable as servants in a newly developed country than in Europe.

At Clausthal or Freiberg, and in Europe generally, it is possible to classify ores as bought, and to specialize the course of treatment given to each class according to the predominance of such elements as arsenic, zinc, bismuth, or sulphur. In America, for the most part, such distinctions are found to be impracticable; no attempt is made to utilize such constituents as sulphur, arsenic, or bismuth, and the greater part of the zinc is wasted. The bulk of the ores being so rich in the precious metals, attention is exclusively directed to extracting these as quickly, completely and cheaply as possible; and in so doing, many valuable by-products are unavoidably lost, which in Europe would be, to a considerable extent, saved. In the United States at the present time, every imaginable kind of mineral substance containing silver is "run through a smelter," unless the precious metal is in the condition of native silver, or as chloride, sulphide, or other amalgamable compound. Calcareous, siliceous, magnesian, barytic, and blende ores, are all purchased by the great smelting establishments, which, in fact, scarcely ever refuse a parcel offered to them; and it is evident that, in order to treat advantageously such a wide variety of ores, large stocks must be carried, and the business must be conducted on an extensive scale; so that any peculiarly refractory consignment may be treated along with an excess of more fusible ores. The methods of extraction in use may be classified broadly according to the agents by which the concentration of the precious metals is effected; the two principal being metallic lead and copper matte. There is also a third medium by which the concentration of precious metals from oxidised ores may

be practically effected, viz., metallic copper; but this has not hitherto been adopted on a large scale, owing to the superior applicability of the other methods to a wide variety in the kinds of ore treated. The Author has, however, met with considerable success on a small scale in concentrating the precious metals by means of this agent; and it would appear that its efficacy is at least equal to that of lead, over which it possesses the advantage of not being volatilized; but the loss in slags is relatively greater than in the case of lead, and the method is not adapted to the treatment of ores containing more than 2 or 3 per cent. of sulphur or of lead; thus excluding a majority of auriferous and argentiferous ores. No distinction is made in this Paper between these two ores, since, in the preliminary extraction, both behave substantially alike, and it is only in the subsequent refining operations that any attempt at distinction between gold- and silver-bearing material becomes possible.

Lead-Smelting.

It is by the employment of lead as a concentrating agent that the greater part of the silver of the United States is obtained. Large metallurgical establishments are at work on this system in most of the far Western States, notably in Utah, Montana, and Nevada: but its greatest development is attained in Colorado, in which State over 700,000 tons of ore were smelted to lead bullion during the year 1891, the chief centres of the industry being Denver, Leadville, and Pueblo. The enormous scale on which the process is conducted, may be indicated by the following figures, reported by the nine largest lead-smelters in Colorado during the year 1891. The total output in lead bullion amounted to 85,621 tons, containing 22,577,758 ozs. of silver, and 142,801 ozs. of gold, the market value of the whole being considerably over £6,000,000.

The apparatus employed for reduction is invariably the water-jacketed blast-furnace with many tuyeres, supplied with air at low pressure, generally about 11 ozs. per square inch. The earliest furnaces were round, 3 feet in diameter at the tuyere-level; but it was soon found that greater economy of working resulted from an increase in the area of the furnace, and soon oval and oblong furnaces, 4 feet by 6 feet, came into use. After many experiments, in the course of which almost every length between 6 feet and 12 feet was tried, combined with the various widths of 30, 33, 36,

42, 48, and 54 inches, it was found that long narrow furnaces gave the best results; and at present the standard type for all additions to plant is an oblong of 33, 36, or 42 inches in width, by 100, 120, or 140 inches in length at the tuyere-level. The early water-jackets of the round furnaces were of riveted boiler-plate, owing to the difficulty of obtaining sound castings; but, with experience, this difficulty has been overcome, and the sectional cast-iron jackets now generally employed last so well, that at the Omaha and Grant works, where six to ten furnaces are kept constantly running, mostly of this type comprising over 100 separate sections, the annual breakage is made good with only a dozen new sections. Many furnace-managers still prefer wrought-iron jackets, even in the largest-sized oblong furnaces, and they are then made in four parts, as shown in Figs. 3 and 4, Plate 3; two side- and two end-sections being bound together by angle-irons and tie-rods. Each section is so constructed as to show no seams to the fire, the edges being strengthened by a frame of angle-iron riveted inside the outer plate; and hand-holes, fitted with cast-iron doors in the usual way, are provided to facilitate the cleaning out of scale and sediment from the water used; the cold-water pipe enters through a cast-iron spout riveted on the top of the jacket, to serve as a hot-water overflow. The chief difficulty with these wrought-iron jackets is that if a patch gets "burnt," or some unusual accretion forms inside the furnace, the whole of that side or end has to come down, which involves dragging out the half-fused mass above the tuyeres—an unpleasant and dangerous undertaking on account of the fumes. If a single cast-iron section cracks or burns, it is easy to shut off the blast and rapidly replace it, without tearing out much of the charge, or otherwise interfering with the regular course of operations. In some works, wrought-iron has been discarded entirely in favour of cast-iron jackets, on account of the economy and convenience of replacement afforded by the latter.

The usual size of a cast-iron section for a standard furnace, 8 feet 4 inches long at the tuyere-level, is 3 feet 5 inches high by 20 inches wide, the iron being $\frac{3}{4}$ inch thick, and the water-space averaging $4\frac{1}{2}$ inches. The cold-water supply and hot-water exit are both at the top of the section; the latter overflows as the former enters, and is carried away by simple galvanized-iron gutters running round the furnace and emptying into the open ends of one or two vertical drain-pipes; these are placed at the corners in such positions as not to interfere with the furnace manipulations, and are connected with an underground discharge-

pipe that runs along the whole length of the smelter-building, and serves all the furnaces. The 14 sections of each complete jacket are planed true at the ends, so as to fit neatly and avoid the necessity for constant luting with fire-clay. Each jacket has a "bosh" of 6 or 8 inches, the slope of which is continued upwards in the brickwork, until, at the top, the area of the furnace is almost doubled; the object of this is to retard the speed of both the descending charges and the ascending gases, so as to ensure the ore being exposed for as long a time as possible to the reducing action of the carbonic oxide formed by combustion of the fuel before the tuyeres. The speed of smelting is of course chiefly dependent on the fusibility of the ore-mixture, and on the volume of air passed through the furnace; and as the tuyere-area generally remains constant, this in turn depends on the pressure of the blast employed; but there is a practical limit for each mixture of ore and fuel, beyond which the speed of descent of the charges cannot be increased without augmenting the losses of lead and silver both in slags and in fume. That limit can only be determined by experience in each particular case.

A few lead-furnaces are charged at the side, as are many copper-furnaces—that method of charging being still preferred by some, as it gives more even layers in a small furnace, and so secures more uniform working; and, in this case, the flue-dust and fumes are often taken away by an overhead "down-take." But, as a rule, the "floor-plate" on a level with the charging-platform forms the top of the furnace proper, an overhead sheet-iron hood, telescoped into a fixed stack, serving to carry off deleterious fumes. A very simple method of almost entirely preventing the escape of fumes has lately been adopted in most of the best works, and will be described hereafter.

The construction of a water-jacketed furnace is illustrated in Figs. 1 and 2, which represent the latest type of furnace as set up during the last few years at the great Colorado smelting-establishments. All the dimensions given in the following description refer to this furnace, which is 36 inches by 100 inches at the tuyere-level. A solid foundation is first formed, 3 or 4 feet larger every way than the base of the furnace, of rubble masonry or brick-work (the latter being preferable), and the foundations for the four cast-iron columns which support the upper part of the furnace are built of large, selected stones. In some cases the foundation has been constructed of molten slag, forming, when cold, one huge slag brick; this is the best of all foundations, but is only attainable for additions to plant in an already existing

works where a sufficiently quick succession of slag-pots can be obtained. When the foundation reaches ground-level, the ¼-inch wrought-iron or steel "foundation-plate" is placed in position, the function of which is to prevent any leakage or loss of lead in case of a crack occurring in the brick-work that forms the bottom of the "lead-well." This foundation-plate has a 1½-inch angle-iron riveted all round it, to assist in keeping in position the heavy "caisson-plates," which surround the lead-well; and it is necessary to pay the greatest attention to the solidity of these, since the constant pressure of a mass of material 17 or 18 feet high on a bath of 30 or 40 tons of molten lead, tends, in the course of time, to force open, as if with a wedge, the most insignificant crack in the brick-work; and, unless the caisson-plates are firmly secured, lead will certainly find its way out.

The caisson-plates are of cast-iron, 1½ inch thick, with strengthening-ribs as shown, and are cast with strong lugs to receive the 1½-inch wrought-iron bolts which bind them together, the edges being planed to ensure good joints. The "well" is built up inside the caisson-plates of the best fire-brick obtainable, a space 2 inches wide being left between the brick-work and the plates, which is loosely tamped with dried fire-clay or other similar material, in order to provide for expansion. The brick-work is carefully bonded, and the mortar used is simply fire-clay mixed thin with water, as little as possible being employed. The end walls of the well are solid brick-work, 18 inches thick, the side walls being 18 inches thick at the top and 2 feet thick at the bottom, except that in the centre of one or both sides is left a channel of the size of one brick, called the "siphon-tap." This leads to the basin-shaped depression in one of the caisson-plates, through which the molten lead issues, and is received in the "kettles." On this brick-work the jackets are placed, with nothing between except a thin strip of wrought-iron; and they are not allowed to support any weight except that of the few courses of fire-brick intervening between their upper surfaces and the "mantel-" or "deck-" plates, upon which rests the superstructure. The mantel-plates are of cast-iron, 1½ inch to 2 inches thick, with an outer flange 3 inches deep, the long side-plates having also a central flange 9 inches deep. The plates first made were often cast too light in the flanges, and had to be strengthened by a course of old rails; but the dimensions now given are found to afford ample strength. These mantel-plates rest upon four cast-iron columns, 8 inches in diameter and 1 inch thick, with flanges between 16 inches and 20 inches

square at both top and bottom. By some manufacturers the deck-frame is made of a thinner cast-iron deck-plate supported on wrought-iron I beams, as shown in Figs. 3 and 4, which is certainly preferable, in view of the rapid changes of temperature to which all parts of a furnace are at times exposed, owing to leaky pipes, &c.; but the construction described here is still the one in most general use. The brick-work of the furnace above the water-jacket is composed of an inner lining of fire-brick, one brick thick, and an outer supporting-wall of selected red brick. The corners of the brick-work "stack," as it is called, are supported in cast-iron buck-stays, 4 inches by 4 inches by $\frac{3}{4}$ inch, each corner being in two sections 6 feet long and provided with six lugs, three on a side, to receive the $\frac{3}{4}$-inch round tie-rods, which bind the structure together. Of late years cast-iron buck-stays have been replaced by heavy angle-iron, which seems to be preferable; although cast-iron often holds its own in the West on account of its being easily replaced on the spot, whereas most articles in wrought-iron have to come from the East.

The brick-work is surmounted by a cast-iron floor-plate, 13 feet 6 inches by 8 feet 6 inches by 1 inch, made in sections with planed butt-joints spliced with wrought-iron plates underneath, 4 inches by 1 inch, a space being left in the centre of the plate to form the charging-hole, 5 feet 4 inches by 1 foot 8 inches, generally oblong in form with circular ends. Immediately below this plate, at the back of the furnace, is the flue mouth, about 2 feet 6 inches in diameter, receiving one end of a "take-off" pipe made of No. 14 sheet-iron, through which, by means of the draught created by a high chimney, the fumes are drawn into long brick flues and condensing-chambers, where a portion of the volatilized lead and silver is recovered, together with nearly all the fine ore-dust carried over by the blast. In spite of the chimney-draught, it was found that a considerable portion of the most deleterious fumes always escaped at the throat and poisoned the men at work on the charging-floor, some of whom were periodically attacked with "lead-colic" or "lead-palsy"; and so every furnace was provided with a telescopic ventilating-hood made of No. 16 sheet-iron, drawing through a pipe about 4 feet in diameter, which somewhat mitigated the nuisance. With the same object, a cover-plate of cast-iron was fitted to the charging-hole, provided with eye-bolts, to which were attached chains running through sheaves fixed in the hood above, and counter-balanced with weights, so that the top of the furnace might be kept closed when not actually receiving its charge. In a furnace

of this description, however, the operation of charging occupies about one-fourth of the whole time of working, so that some fumes always escaped, until the experiment was tried of applying a thimble or sleeve of sheet-iron (No. 3 or No. 4) extending vertically downwards from the charging-hole into the furnace, some 2 feet or 2 feet 6 inches. As this leaves a space between the bottom of the thimble and the walls of the furnace for the fumes to collect in, concentrating the down-draught created by the flue across a smaller area, it is found that the nuisance of fumes escaping on the charging-floor is completely done away with; the cover-plates are abandoned, and even the telescopic ventilating-hood is not nearly so necessary as formerly. The best shape for a charging-thimble is elliptical, or oblong with circular ends; and it is important that its lower edge should reach the level of the bottom of the flue "take-off," in order to trap the fumes effectually.

The furnace is supplied with air by a galvanized-iron branch blast-pipe or "bustle-pipe," 12 inches in diameter, running all round the furnace, connected with the blast-main by a "blast-gate" with a sliding sluice-valve, and fitted with eleven 6-inch nipples for the eleven tuyeres, connection with which is made by ordinary canvas hose, saturated in alum and fastened with copper-wire. The tuyeres are of bronze, bored and turned, tapering to fit into cast-iron bushes which are carefully bored to the same taper as the tuyeres, so as to make an air-tight joint without luting. The bronze tuyeres are riveted to galvanized-iron elbows, each of which is furnished with an iron "sight," containing a glass or mica eye-piece, through which the interior of the furnace can be observed—an indispensable aid to controlling the smelting-process. The water-supply to the jackets is provided by a 4-inch cast- or wrought-iron pipe running round the furnace; being in the former case fitted with reducing T's for the 2-inch connections belonging to each section, and in the latter case drilled and tapped for the same purpose. The supply to each section is therefore independent of the others, and is perfectly controlled by a screw-valve; the object being to limit the circulation so as to keep the overflow as hot as possible short of boiling, both on account of saving water and also in order to diminish loss of heat.

The fuel, ore, and fluxes are always charged into the furnace in separate layers; the fuel goes first and is followed by the ore, the fluxes coming on the top. Sometimes fluxes are dispensed with by properly mixing the various classes of ore; but, as a rule, the quantity of siliceous ore offered so far exceeds other kinds, as

to render necessary some addition of iron-ore and limestone. The fuel is generally a mixture of coke and charcoal, consisting of about 3 or 4 parts of the former to 1 of the latter. Charcoal is at the present time almost invariably dearer than the Western coke employed, and therefore the quantity used is reduced as far as practicable; but replacing it with an equivalent, or even a considerably greater amount, of coke, is found to result in reduction of furnace-capacity, and therefore its use may be considered still general, although every year it becomes scarcer and dearer. During the last few years, some attention has been paid to replacement of the charcoal by an equivalent amount of anthracite or other coal; and experiments in this direction have been encouraging, although not yet affording results sufficiently definite to induce the majority of smelters to abandon the use of charcoal. There can, however, be little doubt that its abandonment in favour of anthracite is only a question of time—so far, at least, as the Colorado smelters are concerned; for the timber in that State is rapidly disappearing near smelting centres, whilst coal deposits of fair quality have been developed on a large scale. The coke employed is usually of a very inferior kind judged by an English standard; being, as a rule, friable and full of little pieces of slate—giving of course a high percentage of ash. Good coke is made on an enormous scale in Pennsylvania, West Virginia, and parts of Tennessee, Alabama, and other States; but these sources of supply are far removed from the smelting-centres; and nearly all of the Western coals are soft and dirty, yielding coke of the kind described. The best of all Western coke is probably that made in the Indian Territory in the Choctaw and Osage country; but even this yields between 11 and 14 per cent. of ash, while the Trinidad, Raton, Starkville, San Pedro, and other cokes from the coal-fields of Southern Colorado and New Mexico, sometimes yield as much as 23 per cent. and average 19 per cent. in large lots. In spite of this inferior quality, it is, relatively, cheaper at all Western smelting-centres than the better coke from the east, and, in fact, wherever delivery by rail can be effected; although in the early days, when it had to be transported 100 miles or more in wagons, it often proved cheaper in the long run to use the best quality of fuel; and these conditions may still hold in the case of some isolated camps. Many metallurgists, moreover, distinctly prefer a soft coke even with the disadvantage of high ash; considering that by its use some augmentation in furnace-capacity is secured over the "hard" cokes; but

it is the Author's opinion that with equal percentages of carbon and ash, hard coke is preferable to soft for all kinds of smelting, as bearing a heavier burden; and this is especially the case where charcoal to give the necessary rapidity of smelting can be procured.

The lead, reduced from its ores by the action of gases resulting from the combustion of the fuel, rapidly sinks through the melting charge; alloying with, and dissolving in its course, practically the whole of the precious metals contained in the ores, and finally collects in the well. A few days after "blowing in" a new furnace, the well becomes filled with molten lead, which begins to overflow through the siphon-tap to a cast-iron spout adapted to the basin-shaped depression in one of the caisson-plates. The stream of molten lead is received in a cast-iron "kettle" about 2 feet 6 inches in diameter, and 18 inches deep, provided with independent fireplace and flue, so as to maintain the temperature of the lead about 100° above its melting-point—too low a temperature increasing the labour involved in ladling, whilst too high a temperature increases the amount of "dross" formed. At intervals of between six and twelve hours, according to the quantity of ore smelted and its yield, the molten lead is ladled into long "bullion-moulds" of thin cast-iron, white-washed to prevent sticking, and is thus cast in pigs weighing between 90 and 120 lbs. each. The chief object of such a large accumulation of molten lead is to equalise the silver contents of the pigs of "bullion," which would otherwise vary so much as to render accurate sampling very difficult, if not impossible. It is probably on this account that all the leading establishments have continued to employ wells on this system as a matter of course; but it would seem, at first sight, that a small outside well in which all the products of fusion could separate into layers, would have the advantage of being simpler and more easily attended to; avoiding the frequent choking of the narrow passages through which the molten lead issues, by masses of chilled matte or speiss, which obstructions often cause hours of hard work in opening a passage and sometimes necessitate blowing out the furnace. This plan possesses moreover the advantage of not locking up some £1,500 worth or more of base bullion in the bottom of each furnace. It was tried by the Philadelphia Smelting and Refining Company of Pueblo, Colorado, in March, 1889; but it was found to produce very foul slags and to add largely to the practical difficulties of furnace management; so that, after running only a month, the outside wells were discarded and the furnaces were re-modelled on the ordinary plan. Outside wells or "fore-

hearths" are, however, successfully employed for separating matte from slag; and their use for this purpose is rapidly spreading for all kinds of blast-furnace smelting, whether on the lead, copper, or matte basis.

The "fore-hearth" or "settler" is elliptical or rectangular in shape, having its longer axis at right-angles to that of the furnace, and is provided with a transverse partition of fire-brick, dividing it unequally—the rear end being only about one-third the size of the fore-part, into which the molten stream from the furnace issues, and which is provided with a cast-iron spout for conveying the slag into the slag-pots in the ordinary way. This partition wall has at the bottom a vertical slot opening of about 9 inches by 4 inches, which is at starting plugged with clay, while the fore-compartment of the well is allowed to fill with the molten product; and, as the matte and speiss sink to the bottom at once, while the slag continuously runs off, this fore-compartment soon becomes nearly filled with molten matte, a condition which is indicated by the slag beginning to carry occasional large globules of it. When this happens, the clay tamping in the slot is knocked out with a bar, and molten matte and speiss, quite clean and free from slag, more than half fills the smaller after-compartment; the surface of the metal even in the fore-compartment being far above the level of the slot, so that only clean matte can come away. The fore-compartment now fills again with slag, which is discharged continuously through the spout into the pots, while the matte sinks to the bottom and passes into the after-compartment, where it is kept hot by a charcoal fire. When the compartment is nearly full of matte, it is tapped into iron or sand moulds in the usual way, by piercing a clay plug in the rear wall situated above the level of the slot in the partition. In this way the matte is obtained clean and in a convenient shape for further treatment. In some cases, the stream of slag from the furnace falls from the ordinary slag-spout into a settler of this description open at the top; but this only works well when the production of matte is considerable; and it is better to have a domed roof to the fore-hearth, and to make connection with the furnace by water-jacketing the side-plate nearest to the tapping-jacket and allowing them to touch; so that an aperture in the former corresponds with the ordinary tapping-orifice in the latter, forming a short pipe, the top of which is below the level of the slag-spout on the fore-hearth. The blast is thus trapped except when matte is being tapped, which operation lowers the level in the fore-hearth for a few minutes. Where the production of matte is small, it is better

to use a simple rectangular settler, open at the top, and to let the slag run through without any partition, changing the settler every twelve hours, or as soon as it begins to "freeze up."

The slag issues from the furnace through an opening in a "water-block" inserted between and below the sections of the water-jacket at one end of the furnace. This water-block is provided with independent water-connections of 1-inch pipe; the hot-water exit being also a 1-inch pipe emptying into the overflow drain-pipe. The tapping-aperture in the water-block is some 3 inches or 4 inches in diameter, and is plugged with clay, through which a small hole is made by the slag-tapper with a $\frac{1}{2}$-inch steel rod, so that the slag may flow continuously and regularly under a head of a few inches trapping the blast. When no settler is used, the slag is received directly in cast-iron pots on small wheels, so as to be drawn by one man if the dump is near, or of larger size on rails drawn by two men or by a horse if the distance is considerable. Occasionally, the molten slag is allowed to fill trucks running on a tramway; the blocks, when cold, being removed from outside the furnace-building by Railway Companies for use as ballast. The Author is not aware of any lead-works where sufficient water-power is available to granulate the molten slag and carry it off by a stream of water; although this method has been successfully adopted at several copper-smelting works and iron blast-furnaces. Water is generally too scarce at lead-smelting works, and has almost always to be pumped a considerable height. In some works the molten slag is thrown away, after having passed through settling-pots to catch the matte and any lead that may have come over; but in the majority of cases it is preferred to rely upon hand-sorting of each potful of slag. The pots are allowed to cool somewhat, and their contents are then deposited on the surface of the dump, where, when quite cold, each slag-cone is broken up by men specially told off for this purpose. It is then carefully examined for a cake of matte, which is generally found at the point of almost every cone, in addition to which there is often a smaller cake of speiss below the matte, and sometimes a button of lead at the extreme point of the cone. The matte contains practically all the copper contents of the original ore, besides a considerable amount of silver, and its treatment will be touched upon hereafter; but the speiss is generally very poor in precious metals, consisting chiefly of iron and arsenic, and is generally thrown away—since, unless containing upwards of 12 ozs. of silver per ton, it will not pay for treatment under the conditions prevailing at most American works.

Of the total lead, silver and gold contents of the ores smelted, an average of about 85 per cent. of the former and 92 per cent. of the two latter are obtained directly in the first instance, as lead bullion and argentiferous matte. Some of the remaining lead and silver is collected in the flue-dust; but by far the larger portion of both elements is irretrievably lost in slags, in intractable speiss, and in the uncondensed fumes allowed to issue from the chimneys after passing through the flues and condensing chambers. In most cases, these are built simply of fire-brick, and no attempt is made to condense, properly speaking—the walls simply aiding natural deposition from the slowly-travelling current of furnace-gases. Sometimes, baffle-walls are introduced to force the current to take a tortuous course; and, more rarely, attempts have been made to increase the surface available for deposition by inserting a number of parallel sheets of iron, which, however, corrode rapidly. But beyond this very little has been done in the matter, and clouds of grey evil-smelling smoke issue from the tall chimneys of almost every lead-works in the country. Experiments have been made with a view to increase condensation by the aid of jets of steam and sprays of water, but the large excess of sulphurous and sulphuric acids in the gases leads to the production of an acid fog which soon destroys the apparatus employed —even the best fire-brick being more or less affected by sulphuric acid; and, moreover, the fume is recovered as a fine mud of sulphates, most inconvenient and expensive to handle, which rapidly corrodes everything brought into contact with it. Up to the present time, therefore, it may be said that there is no practical method available for decreasing the loss in fume except that of increasing the length of the flues, so as to allow more time for impalpable oxides to collect on the walls by surface condensation.

The composition of the flue-dust varies greatly, according to the nature of the ores smelted, that part deposited near the furnace being mainly fine ore-dust mechanically carried over by the blast; whilst, at a greater distance, there is an increased quantity of true "fume"—volatilized oxides, sub-oxides, sulphites and sulphates of lead, zinc, arsenic, antimony, etc. It is removed from the flues at intervals, mixed with varying proportions of either lime or clay, moistened with water, and formed into balls or bricks, either by hand, or, more generally, in a brick-making machine; and, after being dried in the sun or in suitable hot-air chambers, the bricks form part of the regular smelting-charge.

Among the difficulties which have to be encountered by nearly all the great smelting-works at the present time are :—

(1.) The fineness of a large portion of the ores offered. Up to about one-fifth of the whole charge, even "fine" ore, passing a 6-mesh screen, does not perceptibly interfere with the smelting process in large furnaces, except that the quantity of flue-dust formed is much greater than when the whole charge consists of coarse ore, and that the furnace capacity is slightly lessened. Beyond this ratio, however, any increase in the amount of fine ore is attended by many inconveniences, the least serious of which is a great reduction in furnace capacity. Thus, for example, a furnace smelting 80 tons per day when the whole charge is between walnut- and fist-size, will only smelt half that quantity when the proportion of fine ore rises to 50 per cent. Another and more troublesome result is a choking of the furnace, in consequence of which the pressure rises and the zone of fusion is gradually extended upwards, and a large part of the fuel is consumed before reaching the tuyeres, so that there is not sufficient left to give the slag that degree of fluidity necessary to ensure complete separation of the bullion and matte. The worst trouble of all, however, is a gradual sifting down of fine ore through interstices between the coarser pieces, caused by the vibratory motion set up by the blast, until, in extreme cases, cold fine ore pours into the tuyeres, choking them up, and cooling the crucible to such an extent as to necessitate blowing out the furnace. Even when it does not reach such an extreme point, this sifting down of fine ore is attended by the serious consequence of greatly increasing the loss of precious metals in the slag, since such fine ores as reach the crucible to be carried away in suspension by the slag are often barely red-hot and almost unaltered, containing practically the same amount of gold and silver as when they were originally charged. Whenever any large amount of fine ore reaches the tuyeres, the best remedy is to cease charging that quality altogether and to let the charge sink about half-way down the furnace, filling up with alternate layers of fuel, fluxes, and coarse ore—continuing this method of charging for an hour or two under a light blast, until the whole furnace-shaft is filled with coarse material, after which a normal pressure of blast and ratio of fine ore to the charge may be resumed during, perhaps, two or three days, without bad results.

(2.) A second difficulty is the preponderating amount of sulphides in the ore extracted from most great mines in the deeper workings that are situated beyond the influence of atmospheric oxidation. In the early days of lead-smelting in Colorado, nearly

all the lead ores extracted were "carbonates," easily smelted, carrying plenty of oxide of iron to serve as a flux, and so thoroughly oxidized that no preliminary calcination was necessary. At the present time most of the shallow carbonate deposits have been worked out; and, although the same ore-shoots continue downwards below water-level, their metallic constituents, both iron and lead, exist as unaltered sulphides, needing calcination before they can be rendered available—the former as a flux-base, and the latter as a medium for collecting the precious metals. As regards lump ore, consisting largely of iron pyrites and low in lead, the necessary calcination is often effected in heaps in the open air, just as the pyrites-ores of Spain are calcined previously to their treatment by the wet process; but the loss of silver is considerable when the ore is at all rich, and also during wet weather. The process, too, is not suited to fine ores nor to those carrying large amounts of galena or blende, which contain so little sulphur that its combustion does not afford sufficient heat to maintain the process of calcination. The majority of sulphide-ores must therefore be calcined in some appropriate form of furnace, and for this purpose none has proved so effective as the ordinary reverberatory calciner of the Swansea type, with its hearth lengthened so as to obtain the full benefit of the combustion of the sulphur contained in the ore as well as of the fuel.

The most usual type of "roaster," as it is called in America, is a "4-hearth," *i.e.* the length of the hearth is roughly four times its width, although the slope may be continuous from end to end and no step may mark the division between each hearth. To each hearth belong four working-doors, two on each side of the furnace, generally placed opposite one another, although better alternately. A furnace with 4 hearths, each 14 feet to 16 feet square, should deal with between 8 and 10 tons of ore per day if only roasting; but if the charge has to be fused or slagged in addition, the quantity will not exceed 6 tons, and the expense is, of course, proportionately increased. The calcining-hearth of the furnace shown in Figs. 9 to 14, Plate 3, is 58 feet long by 13 feet 4 inches wide in the narrowest part between each pair of working-doors. The fusion-hearth is nearly circular in plan, the radius being 10 feet 8 inches, somewhat resembling one of the old patterns of blister furnace. From the last calcining-hearth to the bed of the fusion-hearth there is a drop of 26 inches; the object being to get the end of the arched roof of this portion of the furnace below the level of the calcining-hearths, so as to ensure the flames being completely reflected

upon the mass undergoing fusion before being spread over the wider calcining-hearths beyond.

Another feature of the furnace illustrated is the utilization of the vaults underneath the calcining-hearths as dust-chambers, Figs. 11 and 13. This is a practice seldom adopted, and has little to commend it except where space cannot be otherwise obtained for suitable flues, whilst the cleansing of dust-chambers in such a position is very inconvenient, and causes an unwelcome addition to the already hot and dusty atmosphere of a roaster-building. In many cases the vaults are completely done away with, the space being filled with rubble stone, or with blocks formed of waste slag from the blast-furnaces; and this course seems to be preferable, at least as regards the calcining-hearth, the temperature of which never rises so high as to endanger the stability of the material composing the bed. It is, of course, necessary to build the fusion-hearth with vaults in the usual way, as the temperature is so high that some of the molten charge would find its way down into the foundations were the bed not kept cool by an air-space below. For the simple roasting of sulphides, especially those rich in lead, when fusion is not desirable, it is better to do away with the fusion-hearth altogether; in which case the level of the fire-box may be somewhat raised and its area considerably diminished, as simple roasting does not demand so large an expenditure of fuel. The bed of the calcining-hearth is composed of a course of fire-brick set on edge as close as possible on a bed of sand, the bricks being laid transversely to the length of the furnaces, and sometimes, for the sake of economy, flat-wise instead of edge-wise. The bed of the fusion-hearth is similarly constructed, except that the bricks are sometimes set on end so as to give double the thickness, being always built in the form of an inverted arch, and that, above the bricks, a layer of crushed quartz or similar material is smelted in together with some slag of high fusing-point, such as a silica-alumina slag; the object being to get an infusible slag bottom about 12 inches thick, which is slightly inclined from the bridge towards the doors, so as to protect the former from being corroded.

When the ore is simply roasted, wood may be advantageously employed as fuel: but its increasing scarcity in the neighbourhood of the great smelting-works has caused its place to be taken to a great extent by coal, of which almost any kind will suit a calcining-furnace, so long as it is rich in volatile constituents, which abound in most of the western coals. If the ore is to be fused after roasting, coal is of course absolutely necessary to give the

requisite heat. The ore is charged by means of a hopper and is gradually passed forward towards the fire end, at a speed varying according to the percentage of sulphur in the ore. When it is to be fused, it is dropped on to the fusion-hearth, containing already a few cwt. of siliceous high-grade ore to form a slag with the ferruginous calcined mixture; and, after an hour or two of hot firing, the whole mass becomes fluid, and is rabbled out into ordinary slag-pots and allowed to cool before being broken up into fist-sized lumps. The object of the fusing-process is to obtain a slagged mass in lumps that can be handled without loss and will help to keep the blast-furnace open.

The difference in the condition of a blast-furnace resulting from the use of slagged sulphide ore instead of merely roasted fine ore, is remarkable. The charge sinks more regularly, the zone of fusion is lowered, the blast-pressure falls, the tuyeres become brighter, and the furnace capacity increases in a marked degree, whilst the "burden," or ratio of ore to fuel, may be much increased. Besides these advantages, the losses in slag and flue-dust are reduced, and, owing to the open charge permitting a more thorough oxidation of the remaining sulphur in the ore-charge, the ratio of matte to bullion produced is smaller. In view of these great advantages, "slagging" or fusing would be universally adopted instead of simple roasting, in spite of its greater expense in labour and fuel, were it not for the excessive losses of both lead and silver involved, especially of the former. The average loss of lead in roasting, supposing the process to be carefully conducted, is found not to exceed 5 per cent. of the quantity present; or, say, on a 40-per-cent. galena ore, only 2 per cent. of the lead will be lost as fumes; and of this, probably one-half can be saved in well-designed flues, of sufficient length and sectional area; while the loss in silver is chiefly mechanical, and, unless the ores contain chlorides, does not exceed 1 per cent. of the total amount present. In fusion, on the other hand, a loss of from 15 per cent. to 20 per cent. of the lead and 3 per cent. of the silver may be anticipated; though a thorough roasting will somewhat lower the loss in subsequent fusion, as the reaction of lead oxide on lead sulphide is the most fruitful source of loss. It is best, therefore, to use as much roasted ore as the furnaces will bear without becoming choked and giving too foul slags; and only to fuse enough to keep the furnaces open—choosing for this purpose ores poor in lead, free from chlorides, and so fine as to risk some loss in handling—such as auriferous and argentiferous concentrates. As the loss of zinc, arsenic, antimony and similar substances, which exercise

a more or less unfavourable influence on the manipulation of the furnace, or on the refining of the bullion and matte, is more considerable during fusion than during the previous roasting, it is also advantageous to fuse all fine ores that are specially rich in any of these elements.

(3) A third difficulty is the enormous preponderance of siliceous "dry" ores over other kinds, and especially over "leady" ores, containing upwards of 15 per cent. of lead. The rich carbonates of lead with considerable basic excess, once so abundant, have now been to a great extent exhausted in most of the Western mining-camps that are within reasonable distance of a railway, and, except as regards the Mexican ores, seem likely to diminish steadily in importance during the next decade. From Mexico, however, large quantities of this kind of ore have been imported annually since about 1885, although the imposition of a duty on the lead of 1½ cents per lb. under the McKinley Act has reduced importations below the point reached a few years ago. Thus the quantity of lead contained in the ore imported during 1891 was only about 22,000 tons, against 28,000 tons in 1888, the year of maximum importation. The Author is unable to procure statistics of the total quantity of this ore imported, but it will now average about 20 per cent. of lead; whereas a few years ago the average was somewhat lower, so that the quantities will be roughly, for 1888, 160,000 tons, and for 1891, 110,000 tons. Nearly all the smelters participate in the benefits of these Mexican ores. Establishments at distances of 1,000 miles or more from the frontier pay for them more than the lead is really worth, and recoup themselves by heavier treatment-charges on the "dry" ores. Still, all the works have felt the scarcity of lead; although, by paying careful attention to the formation of the charges, so as to obtain uniformly fusible slags, the precious metals are successfully concentrated on a percentage of lead which, 10 years ago, would have been thought altogether insufficient. During the first few years of the great Leadville carbonate bonanzas, the average charges treated ran over 20 per cent. lead; but now the Leadville smelters treat an aggregate of over 18,000 tons per month, giving an average monthly output of only 2,100 tons of lead bullion, which is less than 12 per cent. of the ore; while at times, certain works show good results in extraction of the precious metals with only 8½ per cent. to 9 per cent. of lead in the whole charge. This, however, is unusual and cannot be considered safe, except under circumstances of specially fusible ore-mixture, comparatively free from zinc, baryta and sulphur; and, as a general rule, the

ore-charges should not fall below 10 per cent. of lead for steady work and reliable extraction.

In the old German practice, it was usual to employ the litharge resulting from direct cupellation of the lead bullion as an addition to the blast-furnace charge when ores rich in lead were not plentiful; and this was thought to ensure a more perfect collection of the precious metals. The method is still in use in some localities, where modern refining-plant is not available, and where lead ores are very scarce; but it is wasteful and not to be recommended under ordinary circumstances. In most cases, sufficient ores rich in lead can be procured within a reasonable distance of any point likely to be chosen as a centre for custom-work; and it is far preferable, and more economical in the long run, to bring lead ores from great distances and pay a little more than the lead is really worth, shipping the bullion to some large refinery for subsequent treatment, than to adopt direct-cupellation refining, with its heavy loss of precious metals and of the lead itself. In some cases, of course, especially when the smelting-works are intended to treat the ore from certain mines, there is no alternative to the adoption of litharge-smelting with direct cupellation; but, even in this case, it is frequently well to make an effort to increase the supply of lead ore.

(4) Another difficulty in blast-furnace smelting is the large quantity of zinc carried by most of the sulphide ores—sometimes nearly 25 per cent., and often upwards of 10 per cent. Such ores are very intractable, since that portion of the zinc which remains as oxide enters into the slag in that condition and renders it both more pasty and more infusible; whilst, of another portion reduced to metal by the furnace-gases, some goes into the matte and the rest volatilizes; only to be condensed in the upper part of the stack and there form "scaffolds" or "hangings," *i.e.* accretions of ore cemented by metallic zinc, which interfere with the regular descent of the charges, and consequently cause irregularities in the entire smelting-process. In some cases, these scaffolds are so troublesome that the furnace has to be frequently run down to the jackets in order to permit of "barring down," or breaking up these accretions on the furnace-walls by means of long steel bars. It is partly on account of the decrease in furnace-capacity consequent on the large quantity of zinc in the sulphide ores treated at the present time, and partly on account of these troublesome accretions, that furnaces are being built larger both at the tuyeres and in the stack; the largest furnaces of which the Author has any information being 140 inches by 42 inches

at the tuyeres, increasing to 152 inches by 54 inches in the stack.

Zinc has the disadvantageous property of raising the specific gravity of the slag and lowering that of the matte, while it reduces the liquidity of all furnace products, even when present in quantities insufficient to sensibly raise their fusing-points. Hence a comparatively small quantity of zinc renders both the matte and slag produced by a furnace so pasty that perfect separation is impossible; and, consequently, the slag becomes very foul, carrying away minute globules of matte, which increase very greatly the furnace-loss of the precious metals. It is possible to save the greater part of this matte carried away in suspension by a simple means, now in pretty general use in most smelting establishments where the ores are at all refractory. Each pot of slag is allowed to cool for some 10 minutes after being filled, or until a solid "shell" has been formed $\frac{3}{4}$ inch to 1 inch in thickness all round against the iron; the still liquid interior is then poured out, either by pricking the top crust and pouring, or, better, by piercing a clay plug in the lower part of the pot. It is found that practically all the suspended globules of matte have collected in the "shell" of slag so produced, which weighs some 10 per cent. of the whole potful; and this shell so concentrated may be re-smelted; while the only disadvantage of the process, beyond the cost of re-smelting, is the trifling extra labour involved in pricking the pots at the right moment and removing the shells for subsequent treatment.

The Author is indebted to Mr. H. A. Keller, late of Leadville, now of Butte, Montana, for some details of the re-smelting of the rich slags as carried on at the former place during 1891, communicated to the American Institution of Mining Engineers at their Baltimore meeting in 1892. A separate furnace is employed for the re-smelting of slag, being, in the case described, merely an old 36 inches by 80 inches lead-furnace, having its crucible filled with well-tamped sand covered by a course of fire-bricks. The rich slag averaged 5·3 ozs. of silver per ton, and 3,107 tons of it were smelted in one month, together with 402 tons of pyritic copper ores, averaging 10 per cent. of copper, and 11 ozs. of silver per ton. The matte produced averaged 20 per cent. of copper, and 93·3 ozs. of silver per ton, while the cleaned slags averaged only $\frac{3}{4}$ oz. per ton; and the loss of copper in them was insignificant, averaging only $\frac{1}{2}$ per cent., or less. The fuel-consumption was one to ten of charge (as against one to five for the original ore-smelting), and the total expense per ton of material smelted was only $1 47c.,

owing to the efficiency of labour and comparative cheapness of fuel at Leadville. In this instance, the slag flowed from the furnace into an open settler, which was changed every hour; and the cold slag-cones were also broken and picked over by hand to get all the matte. But at some works a fore-hearth like that already described (improperly called a "siphon-tap" fore-hearth), has been employed with even better results—more perfect separation of matte from slag at less expense, and greater comfort to the men as regards fumes, owing to the trapping of the blast.

Attention has been already drawn to the importance of a proper mixture of different kinds of ore for obtaining uniformly fusible slags; and it will be apparent that this is really the all-important point upon which depends success or failure in the smelting business. The following are the general principles or conditions to be observed for good extraction of the precious metals, according to the practice and experience of the best-managed establishments: (1) The slags must never average above 40 per cent. of silica, and, if fluxing ores are available, especially those with large iron excess, it is better to aim at a slag with only 32 per cent. of silica; (2) The amount of lead in the charge should be such as to yield 10 per cent. of the weight of the latter as lead bullion, irrespective of the small amount contained in the matte; (3) The bullion should not run much above 300 ozs. of silver per ton as a rule. Special cases often arise, owing to over-stocking with one kind of ore, in which it becomes necessary to use for a time slags of 42 per cent. of silica, to work with a bullion-yield of only 8 per cent., or to produce bullion of upwards of 400 ozs. per ton; and unremitting care on the part of the whole furnace-staff may enable them to be successful under these conditions. But it may be stated, as a rule, that any departure from the above conditions will be followed by a lower percentage of extraction, and, if continued for any length of time, will exert a prejudicial influence on the annual balance-sheet of the works.

The mixing of the great variety of ores received by a large custom-smelting establishment, so as to comply with the above conditions without overtasking the (usually far too limited) bin-capacity of the works, is a rather delicate operation, to which is devoted the exclusive attention of one assistant, under the direction and supervision of the chief metallurgist. The details of the work are beyond the scope of this Paper, but it will perhaps be advisable to sketch it in outline. The almost infinite variety of ores received may be distributed into certain general classes, more or fewer in number, according to the fancy or custom

of the managers. The following classification is frequently adopted:—

1. Neutral dry ores.	7. Lead carbonate ores.
2. Lime and baryta ores.	8. Galena ores.
3. High-grade ores.	9. Blende and refractory ores.
4. Siliceous dry ores.	10. Siliceous lead ores.
5. Iron and manganese fluxing ores.	11. Concentrates.
6. Low-grade fluxing lead ores.	12. Sulphide ores.

Besides which, the flue-dust, and roasted and slagged ores prepared in the works, have to be reckoned with in making up the furnace-charges.

Two or more of the foregoing are often grouped together; but, whatever classes are adopted, the ore of each class, as it arrives, is unloaded into a bin, into which ores of a similar kind are deposited until it is full, when it is reserved until wanted by the metallurgist to form a required combination. These bins hold from 100 to 300 tons, and are usually built in rows, with a railway running along the back. Their height and area vary according to the levels available, but it is best to make them as high and as small in area as possible, so as to ensure better mixing. The sides are perpendicular, and the back and front frequently so also; but it is perhaps better, when sufficient room can be obtained (which is not often), to make the back sloping at an angle of 45°, to ensure that the portions removed shall be as nearly as possible uniform in composition to the very last charge. Whatever the size and shape adopted, each separate parcel as it is unloaded is carefully levelled over the whole surface of the bin, so as to form an even layer, exactly equal in every part. When one bin has been filled, with, say, 10 different parcels of ore, each of which has been carefully weighed and sampled on its arrival at the smelting-works, a proportionate quantity is weighed out from each of the 10 samples by the chemist; and, after careful mixture, so that the joint sample may accurately represent an average of the contents of the bin, it is analyzed for SiO_2, FeO, CaO, and generally also for one or more of the following substances:—zinc, sulphur, baryta, magnesia and alumina. The lead and silver contents have, of course, been determined for each of the 10 parcels as a basis for purchase, and their average is calculated with greater accuracy than it could be determined directly.

There are several methods in use for calculating the proportions of different ores necessary to give a normal slag, of which that sketched below is perhaps the simplest. The foundation upon which these calculations rest, is that the most fusible of all silicates

of iron is the monosilicate represented by the formula 2 $FeO.SiO_2$, containing 30 per cent. of silica to 70 per cent. of ferrous oxide; while the most fusible of the silicates of lime is the bi-silicate represented by the formula $CaO.SiO_2$, and containing 53 per cent. of silica to 47 per cent. of lime. As a matter of practice, although the bi-silicate of lime slag is slightly more fusible than the monosilicate, it is always preferred to aim at the latter combination, since the increased percentage of lime is found to assist in carrying away sulphur in the slags as calcium sulphide, thus cleaning them and reducing the matte produced. All the iron of the ore is therefore calculated to the composition 2 $FeO.SiO_2$, and all the lime to 2 $CaO.SiO_2$, while any excess of silica has to be reckoned for separately, and neutralized with limestone, which is generally the cheapest flux, though sometimes an iron ore can be procured carrying a few ounces of silver to the ton.

In order to exemplify in a simple manner the method of calculating charges so as to comply with the three fundamental conditions, let it be supposed that the different classes of ore are four, viz.:—

1. Lime and neutral dry ores, comprising Nos. 1 and 2 of the preceding list.
2. Siliceous and high-grade ores, comprising Nos. 3 and 4.
3. Iron and manganese fluxing ores, comprising Nos. 5 and part of 6.
4. Lead ores, comprising Nos. 7, 8, 9, 10, 11, 12 and part of 6.

Of these Nos. 11 and 12 must be calcined before they can enter into the calculation, as also part of Nos. 8 and 9.

Manganese is always calculated as iron; magnesia and baryta are (or should be) calculated as lime, though the latter very often figures as silica, owing to rapid approximate methods of analysis; and, as the amount is generally small, the error is unimportant, especially as it is on the safe side. Ten years ago the magnesia and baryta present in smelting-ores were insignificant in amount, but they now play an increasingly important part in the problem; and, as the silicates of both bases are very much less fusible than the corresponding silicates of lime, it often happens that a special calculation has to be made as to the amount of magnesia and baryta in the final ore-mixture, instead of merely calculating them as "lime." Similarly, it is often necessary to make a special calculation for zinc, so as to minimize the inconveniences already described as arising from an excess of this element. Alumina is not often found in any large quantity in smelting-ores, and may be generally neglected in the calculation of charges, since it may behave either as an acid or a base, and the quantity is not, as a rule, large enough to introduce sensible error by its omission.

Case I.—Let it be supposed that the available quantities of each of the four classes are respectively as the numbers 1, 2, 3, 4, and that their analyses are given in Tables I and II. The metallurgist will first compute the slag components for, say, a 1,000-lbs. charge, on the above proportions of each kind of ore, calculating the silica ratios of the percentages of ferrous oxide and lime present, and noting the number of units in excess, whether of base or of silica, as shown in Table I.[1]

TABLE I.

Ore.		Composition.					Silica Ratios.			Excess in 100 parts.		Total Excess in given Weight.		Bullion.	
Class.	Weight.	Silica SiO_2.	Ferr. Oxide, FeO. Mang. Oxide, MnO.	Lime, CaO. Magnesia, MgO.	Lead per cent.	Silver per Ton.	$=FeO.\frac{3}{7}$.	$=CaO.\frac{5}{9}$.	Total.	Base.	Silica.	Base.	Silica.	Lead.	Silver.
	Lbs.					Ozs.								Lbs.	Ozs.
1	100	20	10	30	5	40	4·3	16·6	20·9	0·9	..	0·9	..	5	2
2	200	60	5	5	2	80	2·1	2·8	4·9	..	55·1	..	110·2	4	8
3	300	10	55	5	5	10	23·6	2·8	26·4	16·4	..	49·2	..	15	1½
4	400	10	30	10	25	20	12·9	5·5	18·4	8·4	..	33·6	..	100	4
										Totals		83·7	110·2	124	15½

In the above supposed case, the totals of basic and of siliceous excess are approximately equal, the difference being only 26 lbs. excess in a 1,000-lbs. charge, therefore no addition of flux is necessary. The charge made up as above contains 124 lbs. of lead, of which, under favourable circumstances, 110 lbs., or, say, 11 per cent. of the weight of ore may be obtained as lead bullion; and, as the total quantity of silver is 15½ ounces, supposing no matte to be produced, and allowing ½ oz. per charge for loss in slag, the bullion will average about 273 ozs. per 2,000 lbs.—the "ton" employed in mining and metallurgical practice in America.

From the above figures, the approximate weight of slag produced

[1] For example, in the 1st ore, 10 per cent. of FeO takes up 4·3 per cent. of SiO_2 for neutralization, while 30 per cent. of CaO will require 16·6 per cent. of SiO_2, or a total of 20·9 per cent. As the ore only contains 20 per cent., there is a deficiency of nine-tenths of a part, which accordingly appears in the column "Basic excess in 100 parts."

from each 1,000-lbs. charge, and its composition, may be deduced thus:—

SiO_2.			FeO.			CaO.		
Lbs.	Per Cent.	Lbs.	Lbs.	Per Cent.	Lbs.	Lbs.	Per Cent.	Lbs.
100 at	20 =	20	100 at	10 =	10	100 at	30 =	30
200 ,,	60 =	120	200 ,,	5 =	10	200 ,,	5 =	10
300 ,,	10 =	30	300 ,,	55 =	165	300 ,,	5 =	15
400 ,,	10 =	40	400 ,,	30 =	120	400 ,,	10 =	40
Totals		210 lbs.			305 lbs.			95 lbs.

If ash be neglected, and some 8 per cent. be allowed for other components, such as sulphur, oxides of lead and zinc, &c., the total slag will weigh some 663 lbs., and its composition will be:

	Per Cent.
Silica	31·7
Ferrous oxide (manganous oxide)	46·0
Lime (magnesia and baryta)	14·3
Oxides of lead, zinc, sulphur, &c.	8·0
	100·0

The above is an excellent slag, fusible and liquid, permitting of easy separation from matte, even when rather cold.

Case II.—If, now, ore No. 1 were to practically disappear from the market, and the flux-ore No. 3 were to become scarcer or much dearer from some cause, whilst siliceous ores were offered in large quantities; so that, of every 1,000 tons accumulated in the stock-bins, only 200 tons were flux-ores, the remaining 400 tons of lead ores remaining as before, the position would be represented by Table II below:

TABLE II.

Ore.		Composition.					Silica Ratios.			Excess in 100 parts.		Total Excess in given Weight.		Bullion.	
Class No.	Weight.	Silica, SiO_2.	Ferr. Oxide, FeO. Mang. Oxide, MnO.	Lime, CaO. Magnesia, MgO.	Lead per cent.	Silver per Ton.	= FeO. $\frac{3}{7}$.	= CaO. $\frac{5}{9}$.	Total.	Base.	Silica.	Base.	Silica.	Lead.	Silver.
	Lbs.					Ozs.								Lbs.	Ozs.
2	400	60	5	5	2	80	2·1	2·8	4·9	..	55·1	..	220·4	8	16
3	200	10	55	5	5	10	23·6	2·8	26·4	16·4	..	32·8	..	10	1
4	400	10	30	10	25	20	12·9	5·5	18·4	8·4	..	33·6	..	100	4
										Totals		66·4	220·4	118	21

This shows a large excess of silica which must be fluxed by the addition of limestone, for which may be supposed a composition of 4 per cent. SiO_2, 2 per cent. FeO, 51 per cent. CaO, the balance being carbonic acid, and the net basic excess equivalent to 25·2 units of silica. Supposing that 400 lbs. of limestone are added to the 1000-lbs. charge, 100·8 units of basic excess are added, bringing up the total to 167·2 against 220·8 of silica; a deficiency of only 52 units on a 1,400-lbs. charge, or about 3½ per cent., which is not too much to allow for zinc, &c.

The total quantities of silica and bases are now:

SiO_2.			FeO.			CaO.		
Lbs.	Per cent.	Lbs.	Lbs.	Per cent.	Lbs.	Lbs.	Per cent.	Lbs.
200 at	10 =	20	200 at	55 =	110	200 at	5 =	10
400 „	60 =	240	400 „	5 =	20	400 „	5 =	20
400 „	10 =	40	400 „	30 =	120	400 „	10 =	40
400 „	4 =	16	400 „	2 =	8	400 „	51 =	204
Totals		316 lbs.			258 lbs.			274 lbs.

Allowing, as before, 8 per cent. for oxides of lead and zinc, sulphur, &c., 921 lbs. is obtained as the weight of slag produced from the charge, the composition being:

	Per cent.
Silica	34·5
Ferrous oxide (manganous oxide)	28·1
Lime (magnesia and baryta)	29·4
Oxides of lead, zinc, sulphur, &c.	8·0
	100·0

This slag is not quite as fusible as that previously described, but it permits of satisfactory separation, and is about the best combination available, unless good iron ore could be obtained cheaply to replace part of the limestone. The amount of lead in the ore-charge is 11·8 per cent., of which amount nearly 10 per cent. would be recovered; and, supposing no matte to be produced, the bullion would average about 400 ozs., which is somewhat high, and points to the necessity of procuring more low-grade lead ores.

It will be understood that the two foregoing examples, being merely illustrative, represent the simplest and most favourable conditions; as a rule, the quantity of siliceous ore available much exceeds that of any other kind; the next largest in quantity is a refractory sulphide ore, rich in zinc, and the problem sometimes

becomes very complex, especially when magnesian and barytic ores enter also into the calculation.

Purchase of Ores.—As a rule, it may be stated that when lead and flux ores are plentiful, the treatment-charges on them rise, while those on siliceous and "dry ores" fall, and *vice versâ*. Silver is always paid for on the basis of New York quotations per oz. (Troy) contained in the ore, with a reduction of 5 to 10 per cent. to cover loss in smelting. When the price of the metal is high, only 90 per cent. of the contents of medium and low-grade ores is paid for; but when low, as at present, 95 per cent. is almost invariably paid, as in the case of high-grade ores. Assays are reported to $\frac{1}{10}$ oz., and payment is made accordingly. Gold, also, when amounting to $\frac{1}{10}$ oz. and upwards per ton of ore, is paid for at 95 per cent. of its full market value, about $18 per ounce. The manner of paying for the lead contents is variable, the principle being to pay for what can be recovered, less refining-charges and freight to the refinery; but a sort of sliding scale is adopted according to the richness of the ore, so as to cover increased loss in working poor ores. Thus, for example, the lead in poor ores, containing between 10 per cent. and 20 per cent., will be paid for at 20 cents to 30 cents per unit, whilst between 30 per cent. and 40 per cent. it will be paid for at 40 cents to 45 cents per unit. Under 5 per cent. of lead is not paid for. Zinc is deducted for; but, as low-grade carbonates and fluxing ores are practically free from it, anything under 8 per cent. or 10 per cent. in the sulphides is often passed; above which standard 50 cents per ton is deducted from the value of the ore for each additional $\frac{1}{100}$ part present. Copper is not paid for in lead ores properly so called (and this is one of the sources of profit); but when ores are bought comparatively rich in copper, and poor in lead, the former metal is paid for at about $1·20 to $1·30 per unit, in which case nothing is paid for lead, whatever its amount, the practice of not paying for both metals together always leaving a good margin for profit in refining.

The treatment-charges vary enormously, according to the quantity of each class of ore dealt with, and its quality. For example, a low-grade carbonate, containing perhaps, 20 per cent. of lead, with 10 ozs. of silver, and upwards of 30 per cent. of basic excess, will sometimes be treated for nothing, or for a nominal charge of $2 to $4 per ton; whilst a very quartoze dry ore, containing 80 per cent. of silica, will have the almost prohibitory charge of $25 per ton put upon it, or perhaps be refused altogether. As a rule, arrangements are made with the principal railways for

reduced special rates, and very commonly a lump sum is charged by the smelter for "freight and treatment," in order to avoid disclosing the rates so obtained. Usually, competition for the scanty supply of lead ores forces down the rate for treating them to the bare cost of smelting, or even lower; while smelters recoup themselves by the treatment of dry ores. These latter are charged for on a sliding scale according to the amount of silica present—a price being from time to time fixed for neutral gangue, that is, for one whose slag-forming components balance, leaving no excess of either silica or base; 10 cents extra per unit being charged for each $\frac{1}{100}$ part of silica in excess; the same amount being allowed for excess of lime, and perhaps 15 or 20 cents per unit when the excess is all iron.

The examples in Table III indicate the usual ratios between various classes of ore; the lowest charges are made by Colorado smelters, and higher charges rule in New Mexico, Utah, and Montana, on account of the higher price of fuel. In any particular locality, however, it may be said that low charges on lead ores correspond with high charges on dry ores, and *vice versâ*.

TABLE III.

Classes of Ore.	Lead per cent.	Silver, ozs. per Ton.	SiO_2 per cent.	FeO per cent.	CaO per cent.	Sulphur per cent.	Treatment-Charges.	
							Leadville, Denver, Pueblo } Col.	El Paso, Texas. Socorro, New Mex. Salt Lake, Utah. Helena, Montana.
							Dollars.	Dollars.
1. Low-grade flux carbonates	20	10	5	35	15	..	2 to 3	3 to 6
2. High-grade carbonates	40	50	10	15	10	..	3 „ 4	4 „ 8
3. Galena	60	80	..	5	..	15	10 „ 14	12 „ 16
4. Argentiferous iron .	3	12	10	60	5	..	4 „ 5	4 „ 8
5. Neutral "dry" . .	2	40	20	15	25	..	10 „ 12	14 „ 18
6. Siliceous	2	60	70	2	5	..	16 „ 18	18 „ 22
7. Pyritic sulphide . .	20	50	5	35	..	30	12 „ 16	16 „ 20

The argentiferous iron mentioned in the Table is more generally paid for on an entirely different basis; when containing less than

12 per cent. of silver, no treatment-charge is made, and, instead of 95 per cent. of the silver being paid for at New York rates, the whole contents are paid for at 45 cents to 50 cents per ounce; but an excess of iron and manganese over silica, equal to at least 40 per cent. of base, must be guaranteed, in order to secure these favourable prices.

Description of the El Paso Smelting Works.

The Author is permitted to give the following detailed description of the El Paso Smelting Works, situated on the left bank of the Rio Grande at Towne, 2 miles above El Paso, Texas, owned by the Consolidated Kansas City Smelting and Refining Company, of Kansas City, Mo., perhaps the largest smelting corporation of the west. Through the kindness of Messrs. H. Huber, General Manager of the company, and P. Henderson, Superintendent of the El Paso Works, the Author has been afforded every facility for examining the plant, and the operations conducted therein.

The works were established in the summer of 1887, at a point about 300 yards from the river, between the two trunk lines of the Southern Pacific, and the Atchison Topeka and Santa Fé Railway Companies, which at this point run nearly parallel for some distance, and from each of which a siding has been taken into the works. There is plenty of room for slag-tips for some years to come, and already considerable quantities are being removed by the Santa Fé Railway for ballast. The only unfavourable feature of the situation is the want of suitable levels for the ore-bins; consequently some dangerous shunting has to be done on trestle work, and all the ore, &c., has to be raised by an elevator to the charging-floor; but this is, after all, an affair of comparatively slight importance, seeing that the slag for re-smelting would have to be raised in any case.

At first, only 2 small stacks were built, which have been replaced by larger ones, and added to, until in August, 1892, 8 stacks were in place, of which 6 to 7 are on an average constantly running; the quantity of ore smelted in 12 months being between 70,000 and 80,000 tons, besides 25,000 to 35,000 tons of flux, 1,800 to 2,000 tons of flue-dust, and 25,000 tons of slag re-smelted. The annual fuel bill includes some 2,500 tons of charcoal, and 16,000 to 18,000 tons of coke. The annual product of lead bullion is between 11,000 and 12,000 tons, and of matte about 3,000 or 4,000 tons. The works are being

enlarged, and the above figures, which refer to 1891, will probably be considerably exceeded during 1892.

A sketch-map of the works is given in Plate 3. Truck-loads of ore brought in over either of the two railway-sidings are first passed over the weigh-bridge, where the number and gross weight of each truck is taken, the tare of the truck being checked after unloading. For moisture, a "grab sample" is at once taken to the assay office; but the process of accurate sampling is carried on during unloading, every tenth shovelful being thrown into a heap on the floor of the car as the remainder is shovelled out into the "mixture-bin" or "receiving-bin," as the case may be. In the case of consignments from regular customers, or ores of well-known character, the cars are unloaded direct into such mixture-bins as may be pointed out beforehand by the metallurgist; but ores whose character is not well known are unloaded into a "receiving bin," of which there are about 60 on the premises, of a capacity varying between 10 tons and 20 tons each; and in these the ore is retained if so desired by the seller until the results of assays are received and approved. With low-grade ores, only 1 shovelful in 20 is left on the floor of the truck as a sample; with high-grade ores, 1 shovelful in 5; and when the lot consists of 2 tons or less, the whole is quartered down. In every case, the sample is wheeled on to a platform at one end of the sampling-house, where it is passed through a small Dodge crusher, if necessary, to pass a $\frac{3}{4}$-inch mesh. It is wheeled on to the sampling-floor, formed of 2-inch tongued-and-grooved oak planks, where four men with shovels first spread it into a ring, then throw it into a heap in the centre, and quarter it down in the Cornish fashion until only two or three barrowsful are left. The reduced sample is wheeled on to the crusher platform and passed through a "coarse-crushing" set of Cornish rolls 10 inches on the face by 20 inches in diameter, crushing it to about a No. 4 mesh. It is then cut down once and re-ground through another set of rolls, which reduce it to pass through a 10-mesh screen. It is then quartered down again and again until only some 20 lbs. are left, when the residue is passed into the "bucking-room" to be sifted through a 12-mesh sieve, the coarse part being ground in a sample-grinder of the coffee-mill type. After grinding and mixing, the quartering is continued until the sample weighs only a couple of pounds, when it is all bucked down on a carefully-cleaned bucking-plate and passed through an 80-mesh sieve; the final sample being filled into 5 paper-bags holding about 6 ozs. each, which are all

sealed; 2 of these are delivered to the assayer with the ticket giving the lot, number, weight, &c., one is given to the seller of the ore, whilst the others are reserved in case of dispute arising.

The mixture-bins at the El Paso works vary in capacity from under 100 tons up to 250 tons, their total capacity being some 6,000 tons, or nearly one month's stock for all the furnaces. There are two separate series, as shown in the map, each series being composed of pairs of bins extending outwards from a central scaffolding that carries the line of rails on to which the cars are shunted. The walls of the bins are about 8 feet high, and the floor is planked so as to facilitate shovelling and clean sweeping. The gangways between the bins are also planked, while there is a track in the centre of each for the little iron tram-wagons that hold about 10 cubic feet. In a central position is the charging-scale, situated in the centre of a space floored with cast-iron plates $\frac{1}{2}$-inch thick, to which all the tramways converge, and which allow the tram-wagons to run easily in any direction over them. The charging-scale has 8 independent beams for weighing as many different kinds of material, and close to it, on both sides, are small charging-bins holding the different kinds of ore, slag, flue-dust, &c., that form the charge for the time being. These small charging-bins are kept constantly replenished from the different mixture-bins by a special gang of men, whilst another gang fills the charging-wagons as they stand on the scale-platform under the eye of the charge-weigher, who releases each of the beams in turn as required. Usually, the ore and flux for each charge goes into one of the charging-wagons, and the coke, charcoal, and slag into another; the two being then run into one of the cages of a steam-elevator in which they are hoisted to the charging-floor, 2 empty wagons coming down at the same time in the other cage. All the furnaces take the same charge simultaneously as a rule; therefore, once on the charging-floor, the wagons go to that furnace which first "drops," making room for another charge.

All the furnaces have been re-modelled during the past two years so as to be identical in dimensions; and spare sections of jackets, &c., are all interchangeable. The size at tuyere-level is 42 inches by 120 inches. The type is identical with that shown in Figs. 1 and 2, except as regards dimensions. All the furnaces are arranged side by side in one large shed, are provided with identical ventilating-hoods, charging-thimbles, &c., and draw into one series of flues and dust-chambers. One general blast-

main runs along the entire length of the furnaces, being 42 inches in diameter at the blower-end contracted to 30 inches beyond No. 3 furnace; and the blast is supplied by a miscellaneous set of Baker and Root blowers, chiefly the former, driven by belts and counter-shafts from either of the two engines. These are a Hendey-and-Meyer 100 HP. (nominal), the ordinary speed of which is about 108 revolutions, and a Porter-and-Allen so-called "high-speed" engine of 125 HP. (nominal), generally running at about 200 revolutions per minute. One of the two Baker blowers is kept in reserve, while only one of the engines is run at a time, the other being kept in reserve. The blowing-machinery is placed in an engine-room, which contains also a small engine driving the dynamo that generates electricity for lighting the works, offices, &c.; the engine and dynamo being together under a glass case that is counterbalanced so as to be readily lifted for oiling and inspection. Steam is supplied by 5 multitubular boilers of 80 HP. each, which serve the pond-pumps and small crusher and elevator engines, as well as the principal blowing-engines, the usual working-pressure being 90 lbs.

The water-supply is obtained from the Rio Grande, 63 feet below the level of the works, the pump-house at the river containing two horizontal double-plunger Dean pumps, with a 12-inch steam-cylinder and 7-inch plunger, and a 14-inch steam-cylinder and 10¼-inch plunger respectively; the stroke of each being 10 inches, and the total ordinary capacity of the pumps being 750,000 gallons per twenty-four hours. As a rule, it is not necessary for these pumps to develop more than one-third of their full capacity, since the hot water from the general drain-pipe runs into 4 large cooling-ponds, whence it is returned by another set of Dean pumps into a wooden tank, the bottom of which is about 10 feet above the top of the jackets, so as to give considerable pressure. The pond pump-house contains two Dean pumps of 10 inches stroke, the diameter of the cylinders being 12 inches and 10 inches with 7-inch and 6-inch plungers respectively, and the total daily capacity 650,000 gallons per twenty-four hours.

The storage-bins for coal and limestone are shown in the map. With the exception of a few hundred tons retained for emergencies, no stock of coke is kept, as the Santa Fé Railway supplies three or four truck-loads of 15 tons per day as required, with considerable regularity, and the coke is used direct from the trucks, involving some saving in handling. As a rule, coke from Southern Colorado, controlled by the Santa Fé Company, is used on account of the supplies being more easily regulated. The limestone is

quarried only a mile from the works, and the contractor delivers it as required, broken to a specified size, for 70 cents per ton, f.o.b. trucks. An additional flux, in the shape of old tin-cans, sheet-iron, and similar scrap, is employed whenever it can be obtained in sufficient quantity, 20 to 30 lbs. being put into each charge. This serves the double purpose of helping to keep the very fine charge open, and of ensuring the presence of a certain amount of metallic iron besides what may be reduced from the slag. It is found that a certain proportion of metallic iron in the slag is absolutely essential to a perfect extraction of the precious metals. This old scrap, including large quantities of old tin-cans, is bought at $9 per ton delivered at the smelting-works.

The offices, laboratory, store-rooms, &c., are situated on the east side of the storage-ponds. The ore-purchasing department is in the town of El Paso, being connected with the works by a private telephone. Very good houses are provided by the company free, or at a nominal rental, for all the employes. To the west of the sampling-house is the roaster-house, a large well-ventilated building containing 4 long reverberatory calcining-furnaces of the usual pattern, 2 of them being provided with a "fuse-box" or "slagging-hearth" next to the fire-box, as shown in Figs. 9 to 14. These "roasters" are chiefly used for roasting matte, and for calcining concentrates from gold and silver mills and jig-concentrates from galena mines, though the quantities received are comparatively small. There is no need to roast sulphide ores as at Leadville for flux, because the works enjoy the special advantage of large supplies of low-grade carbonates with considerable basic excess, from Sierra Mojada, Mexico; and, moreover, receive consignments of low-grade silver ore from Tombstone, Arizona, nearly free from lead and rich both in manganese and iron. The carbonates from Mexico amount to 35,000 or 40,000 tons per annum, forming one-half of the total amount treated. They contain an average of about 25 per cent. of lead and 22 ozs. of silver per ton, with such an excess of iron as to render them most valuable as flux. Frequently, indeed, the furnaces have been run for short periods entirely without other flux for siliceous ores than an excess of these carbonates; but they run very high in fine ore, and accordingly lead to the production of considerable quantities of flue-dust, besides reducing the furnace-capacity to some extent. The cost of roasting is high, $5 per ton, and for this reason also the quantity of ore roasted is kept as low as possible. To the south of the roaster-house is the roast-yard for matte, where the first matte is partially roasted in open heaps before its calcination

is completed in the roasters, where it is re-smelted to a second matte with the addition of siliceous ores containing copper and silver; which flux the oxidized iron, and therefore indirectly raise the product to a higher grade, besides directly increasing its silver and copper contents. Roasting-stalls for matte are now being substituted for the open heaps, with the object of accelerating the process and diminishing loss. The second matte is only prepared at intervals, and is at once sent to the Argentine Works, Kansas City, where all the products of the various smelting-works owned by this company are brought into a marketable state; soft lead, ingot-copper, bar-silver and gold being all turned out in a refined condition. The pigs of lead-bullion are also despatched to Argentine daily, each consignment consisting of one or two truck-loads of about 18 tons each.

A variable amount of poor speiss is produced in the furnace, sometimes, though rarely, amounting to two or three tons per diem. It generally contains between 10 ozs. and 12 ozs. of silver per ton, but this amount is not sufficient to encourage much dealing with such an intractable material. The speiss when produced at all, is found as a separate layer at the extreme point of the cold slag-cones, which are at El Paso all broken and picked over, rather than trust to any matte-separator, settler, or similar device. As cheap Mexican labour is employed to do this work under trustworthy foremen, the system has much in its favour; yet, in the Author's opinion, better results would be obtained by employing a suitable settler for the molten slag; since any lead coming over with the latter into a slag-pot, remains molten for a long time and splashes about when the pot is dumped. The flue-dust is withdrawn at intervals from the chambers—the end nearest to the furnaces requiring to be cleaned every week—and is placed in a large wooden tank about 3 feet deep, together with about 5 per cent. of its weight of plastic clay, water being added and the whole well trodden and mixed. It is then allowed to dry in the sun until of the consistency of brick-clay, and it is passed through a pug-mill; after which it is formed by hand into bricks, which are allowed to dry in the sun for a few days before being used. The operation of pugging and making the bricks is done by contract at $3 per 1000; but cleaning out the flues is paid for by day-work, men being detailed for short periods from the large force that is always occupied in sorting slag on the dump; each one working only a little while, on account of the danger of being poisoned by the fumes and fine dust, notwithstanding that wet cloths over the mouth and nostrils are employed as respirators.

Smelting-Works at Las Trojes, Michoacan, Mexico.

As a contrast with the works described above, reference may be made to those of the Michoacan Land, Railway, and Mining Company of Las Trojes, Michoacan, Mexico—an establishment that smelts argentiferous ores derived almost exclusively from its own mines. At these works are 2 furnaces, with wrought-iron jackets 84 inches by 33 inches at the tuyeres, made by Messrs. Fraser & Chalmers, of Chicago, resembling that shown in Figs. 3, 4 and 5, Plate 1. The works possess the advantage of water-power for blowing and other purposes during the greater part of the year—a 6-feet Pelton wheel, under a 500-feet head, giving as much power as would suffice to run half-a-dozen such furnaces. Four No. 5 Baker blowers, supply air for the two furnaces. The ore raised from the mines is very sulphurous, carrying a large amount of iron pyrites, for which reason the calcination is performed very simply in open heaps called "caleras," and corresponding with the "teleras" of the Spanish pyrites region. The calcination is, however, imperfectly performed in wet or windy weather, and occupies a long time. During the past year, roasting-stalls have been partially substituted for open heaps, with great advantage as regards the rapidity and thoroughness of the calcination and the loss of silver.

The quantity of lead in the ores is small, and, as lead-ores are rather scarce in the district, the direct-cupellation process is adopted; with the double object of promptly utilizing the silver without locking up a large amount of capital in bullion-shipments to England or in expensive refining-plant, and of getting the litharge as an addition to the charge. As the furnaces are, however, unprovided with suitable flues and dust-chambers, the loss of lead and silver is considerable, and can only be justified by the lack of capital for making necessary modifications in the works or for carrying large stocks of bullion. The pigs of bullion are refined in a "vaso" or cupelling-hearth of the ordinary German pattern, with a removable hood, the silver bullion going direct to the Guadalajara Mint for coinage. Table I, Appendix, shows a comparison between certain details of the El Paso Smelting Works with those of Las Trojes. In order to compare costs, both sets of figures have been reduced to English money, the American dollar being taken at 4·86 per £1 sterling, and Mexican silver at

$6.50 per £1 sterling, which are the average ratios for the past three years.

The coke used at Las Trojes is obtained from Colorado, and costs nearly twice as much as at El Paso. The unusually cheap rate at which charcoal is obtained in the neighbourhood, nearly compensates, however, for the high price of coke. It will be at once noticed that, at Las Trojes, the ore forms a comparatively small part of the total quantity treated in the furnaces, the remainder being made up of roasted matte, slag and litharge, together with a small portion of limestone, the necessity for which is not apparent, seeing that the ores already contain a large excess of base. The amount of matte produced is relatively enormous, and possibly the addition of limestone assists in carrying away more sulphur in the slag as calcium sulphide, but the real remedy lies in better calcination of the ore. To throw back matte into the ore-furnace is bad practice, and it would be far better treated separately after thorough roasting, with the addition of siliceous ores, and, if necessary, a little litharge. The amount of slag re-smelted is also excessive, and might be diminished by adopting some suitable form of separator or settler. The bullion is, moreover, far too low-grade for economical refining. Seeing that the poverty of this bullion is due only to expensive and excessive additions of litharge, the process followed must be described as antiquated and wasteful. In silver-smelting, beyond all other branches of metallurgy, such gigantic strides have been made within the past 15 years as to completely revolutionize the art. Although the principles remain the same, the best modern practice is entirely different in all its details from that of a few years ago. The aim nowadays is to turn out products of as high a grade as practicable, without increasing too much the losses in slags and in flue-dust; since the higher the grade of the product, the smaller will be its bulk, and the less the expense of handling and the loss in refining.

Extraction by means of Metallic Copper.

This process is to some extent the result of an accidental discovery. It was found long ago that in smelting certain oxidized ores of copper, any small quantity of silver and gold contained in the ores became perfectly concentrated in the resulting pig-copper, from which, if in sufficient quantity, the precious metals could be

separated by the electrolytic process, or even in the dry way, if very rich. By an extension of the method, ores containing copper in an oxidized condition may, under certain circumstances, be smelted with other ores rich in silver, the copper of the former serving as the vehicle for concentrating or extracting the whole of the precious metals from both classes of ore, exactly as lead is employed in the ordinary smelting process. The extraction is quite as perfect as in the case of lead, and there is no loss by volatilization; but the loss of copper in slags is relatively of greater importance than that of lead in the ordinary process, on account of its higher intrinsic value, copper being worth from two-and-a-half to four times as much as lead in the United States, and slightly more in England. This disadvantage is, however, compensated by the fact that the rate of concentration may be increased to as much as 20 to 1 as against 10 to 1 on a lead basis, so that charges can be dealt with containing only 5 per cent. of copper, instead of 10 per cent., which is the minimum for lead. The greatest drawback, however, to a more general application of the process is, as already mentioned, the scarcity of ores rich in the precious metals, and nearly free from both lead and sulphur, not being milling-ores. The former element only interferes by combining with the copper, forming alloys that are both difficult and expensive to refine, and consequently anything over 1 per cent. of lead in the whole ore-charge detracts considerably from the value of the resulting base bullion, as will be seen hereafter. With regard to sulphur, this element, if present in a higher ratio than 1 or $1\frac{1}{2}$ per cent., influences the result by forming a considerable quantity of matte, which is more expensive both in freight to the refining works and in subsequent treatment, while 4 or 5 per cent. is sufficient to "throw back" the whole furnace-product into the less valuable form, and the process then becomes matte-smelting pure and simple.

Smelting at Terrazas, Chihuahua, Mexico.

The following description of smelting operations carried out by the Author at the Torreon Mines, Terrazas station, Chihuahua, Mexico, may be found to possess some novelty. The furnaces employed are identical with those in use in Arizona for smelting oxidized ores of copper, and their manipulation has been already well described by Dr. Ed. Peters, jun., in his work on "Modern American Methods of Copper Smelting." The Author has, however, had several years of experience in producing pig-copper of

superior quality, direct from ores of much poorer quality than those described by Dr. Peters, and probably poorer than any ores before smelted to pig-copper at one operation. It may therefore be interesting to record some of the results obtained. The furnace used was an ordinary 36-inch round water-jacketed furnace, built by Messrs. Fraser & Chalmers, of Chicago (Figs. 6, 7, and 8). This is not by any means the most modern form of furnace for smelting ores of even moderate richness, and, when applied to poor ores, has shown certain special defects which will be subsequently alluded to. The dimensions are given in the Figs. referred to, from which it will be also noticed that the material is all wrought-iron, except the bottom plate with its drop-doors, and the supporting columns. These drop-doors are designed to be used in cleaning out the crucible after "blowing-out" the furnace; but they are quite unnecessary, as in ordinary circumstances skilful management will leave the bottom in better condition at the end of two months' working than when the furnace was first blown in. On the one or two occasions, when some temporary breakdown in the blowing-machinery or water-supply has resulted in "freezing" the contents of the crucible, the Author has found it easier to lift up the furnace-stack by screw-jacks placed over the four short cast-iron foundation columns, and to remove the "bottom" of chilled copper, slag, etc., in one mass, breaking it up outside with the help of dynamite. When smelting poor ores, it has also been found advantageous to wall round the open space below the bottom plate and between the foundation-columns with slag-bricks, plastering the interstices with clay, so as to shut off all circulation of air beneath the furnace; this helps to keep the bottom hot and to prevent chilling, when low-grade ore yielding only a small amount of metal is being smelted.

As regards the crucible-lining, the usual practice is to put in one course of 9-inch key fire-bricks made to the same radius (18 inches) as the furnace, and, inside this, to ram a lining of "steep," which is subsequently cut to a convenient shape. As ordinary fire-bricks cost about 5*d.* each delivered at the furnace, and having within 8 miles a quarry of soft refractory trachyte rock, the Author has found it advantageous to use blocks of this stone cut to the proper curve for the parts of the crucible round the copper and slag tap-holes, filling up the remaining space with a mixture of 3 parts of pounded stone of the same kind broken to pea-size and 1 part of the best clay obtainable, moistened as little as possible and tamped evenly into a solid mass. This is, while still damp, cut and smoothed into such a shape as will permit of every part of the

crucible thus formed being reached by a bent bar. The tamping is done with bars of $1\frac{1}{2}$-inch round iron upset at one end to 3 inches in diameter, heated in a small forge and changed as often as they get cold. The pounded stone is thus formed into a homogeneous block, which, after being dried and baked by a wood-fire, becomes like a solid fire-brick. Whatever be the nature of the furnace-lining, it only lasts, as a rule, between 6 and 10 days; nor is it required to last longer, since, after the original lining has been completely burnt out above the slag-tap, the furnace is run simply on a lining of chilled slag, the thickness of which may be regulated at will by spraying water on the outer iron casing when too thin, or by adding two extra charges of coke, emptying the furnace of its fused products, and "blowing" through the "copper tap-hole" if too thick and cold. By working on this plan, the life of a single lining is dependent only on external conditions, such as the length of time that the machinery will run without being overhauled, deposits of scale in the jackets caused by the impurity of the water, slight breakdowns in the pumping- or other machinery, deficiency of fuel or of ore, etc. As a rule, it may be reckoned that, where only a single furnace is worked, some one or other of these trivial accidents is sure to happen within a period of between 4 and 6 weeks; although, in large establishments, furnaces of this description have been kept at work for a year or more without difficulty.

The quantity of ore which can be smelted in a furnace of the pattern described, depends upon the degree of fusibility of the charge and its mechanical condition. As a general rule, it is necessary in small and low furnaces to break down ore and flux to a much smaller size than is necessary or advisable in the case of the large furnaces employed for lead-smelting. Into these small furnaces, no lumps of more than fist-size should be admitted, and a distinct benefit is found to result from breaking all siliceous or otherwise refractory lumps to the size of walnuts. The difficulties and irregularities introduced by too large a ratio of fine ore in the charge, are, however, felt even more in these small round furnaces than in the large oblong ones; so much so that 25 per cent. of fine ore in a 36-inch round furnace gives fully as much trouble as 40 per cent. in a furnace of 36 inches by 100 inches, or upwards, with a bosh. The size of the fuel, too, is a matter of much importance. Large pieces of coke should not be allowed to pass the feeder, unless of prismatic form, when 9 square inches in sectional area should be a standard maximum. On the other hand, it is found that pieces smaller than a walnut either get

burnt up before reaching the tuyeres, or else become enveloped in slag, which protects them from the action of the blast; so the fuel should be kept as far as possible within these limits of size in order to secure good results. As regards the absolute quantity of each charge, the Author's experience is in favour of small charges for these furnaces when smelting poor ores; having found that, other conditions being the same, the slags are invariably more free from copper and from silver when small charges are employed. A practical limit as regards smallness of charges is, however, soon reached; since the pile of coke before the feed-door, corresponding with each charge, must be large enough for the feeder to spread it evenly over the whole area of the furnace, making a distinct, if thin, layer. The best results have been given by a charge of 90 lbs. of fuel, corresponding with 450 lbs. to 520 lbs. of ore, according to the richness and fusibility of the latter and the quality of the former.

The slag runs from the slag-spout into a suitable form of settler, made of cast-iron plates bolted together and lined with fire-clay, standing on a thick bottom-plate, provided with 4 wheels. In this, nearly all the shots of copper mechanically carried over have time to settle, besides a small part of the combined copper, which is precipitated and collected by the aid of scrap-iron, old tin cans forming the best possible scrap for this purpose. From the spout of the "settler" the stream of slag runs into the ordinary slag-pots, which, when full, are at once wheeled away and emptied, as the amount of copper in them, other than that in combination, is quite insignificant—less than $\frac{1}{4}$ per cent.—and this as shots of matte, not copper. An erroneous impression seems to prevail about the amount of shot-copper necessarily carried away in these slags. Even Dr. Peters, in his generally accurate and exhaustive description of copper smelting in Arizona, already referred to, says:[1] "The average slag-assays from the smelting of oxidized ores in water-jackets may be estimated at 1·75 per cent. of copper, consisting of about equal portions of oxidized and combined copper and of minute metallic globules." According to the Author's experiments, this is incorrect. The amount of shots of metallic copper of $\frac{1}{100}$ inch in diameter and upwards, which pass the settler when running a fusible slag, does not average $\frac{1}{20}$ per cent., whilst the quantity of shots of high-grade matte will not exceed $\frac{1}{10}$ or $\frac{2}{10}$ per cent. Practically speaking, all the copper contained in

[1] Ed. Peters, Jr. "Modern American Methods of Copper Smelting." 3rd Edn. 1891, p. 214.

Torreon slags is oxidized and combined; most of it is extracted rapidly by the action of very dilute boiling hydrochloric acid, part being re-precipitated instantaneously upon minute particles of reduced metallic iron, of which the slag is full. According to reliable information furnished to the Author privately, it is indeed true that the slags at Clifton, Verde, and other Arizona mining-camps, have often contained as much copper in shots as in combination, when smelting oxidized ores; but the total contents, when accurately sampled, then reach nearly 3 per cent. of total copper, instead of $1\frac{3}{4}$ per cent., as stated by Dr. Peters. This loss is due to over-driving the furnaces, with a view to increasing the output and decreasing the cost of production; but, although common in Arizona, is not admitted by the furnace-managers, who endeavour to produce slag-samples for assay free from shots and low in combined copper.

When smelting the poorest kind of ores, especially if rich in silica, it is found that the slag-assay rises appreciably; and, even with ores of moderate richness, the loss seems high, although completely explained by the high grade of the product and the entire absence of the reducing action of sulphur, as the same furnaces using sulphide ores and producing a matte of, say, 35 per cent., will turn out slags not exceeding $\frac{7}{10}$ per cent. in their copper contents. With cheap fuel the loss might be considerably reduced, but fuel is too dear at Torreon to encourage efforts in this direction. Experiments seem to show that, in these low furnaces with nearly perpendicular sides, the ore is not exposed for a sufficient length of time to the reducing action of furnace-gases. An obvious remedy is to increase the height of the furnace and the area of its upper portion. It is now contemplated to replace the present type of furnace by a much larger rectangular one, the shape of which above the tuyeres is that of a frustum of an inverted pyramid, the area at the charging-platform being about double that at the tuyeres; and there can be no doubt that better results will follow the carrying into effect of this project—a similar change having been effected in several of the Arizona plants. Table IV shows the composition of slags produced at Torreon, column A giving that of a normal slag produced from copper ores only; column B, an abnormal siliceous sticky slag, produced at one time when smelting siliceous second class ores only; whilst, for the sake of comparison, C gives the composition of some slag produced in an Arizona copper-furnace, working with $14\frac{1}{2}$ ore—these figures being extracted from Dr. Peters's work already quoted from :—

TABLE IV.

	A. Torreon Normal Slag.	B. Torreon Siliceous Slag.	C. Arizona (Dr. Peters's).
	Per cent.	Per cent.	Per cent.
Silica, SiO_2	39·41	50·05	36·5
Ferrous oxide, FeO	36·14	29·75	40·0
Alumina, Al_2O_3	4·26	5·25	6·7
Lime, CaO	17·24	11·00	13·0
Magnesia, MgO	0·21	0·70	0·0
Suboxide of copper, Cu_2O	1·88	2·08	1·9
Sulphur, zinc, alkalies, &c.	0·86	1·17	1·9
	100·00	100·00	100·0

The copper is tapped at intervals with a 1-inch pointed steel bar into oblong moulds on wheels, as in the ordinary Arizona practice, with the difference that the small quantity of metal produced prevents such frequent tapping, and, consequently, greatly increases the difficulty of the operation. As a rule, tapping takes place every hour, producing a pig of between 150 lbs. and 250 lbs. in weight; but, when the furnace happens to be running a little cold or irregularly, the breast is often very hard, and sometimes it occupies four men pounding away with 12-lb. sledges as long as half-an-hour, in the course of which half-a-dozen steel bars are blunted or broken, before an entrance can be effected. When running steadily, however, and not stinting fuel, the bars can be got out regularly every hour with very little variation in size, and without much trouble, provided that the head tapper, or working foreman, is skilful at keeping the breast and tap-hole in proper condition—an operation much more difficult to perform with metallic copper than with matte, which melts at a lower temperature and does not chill so rapidly.

At Torreon, there are two 36-inch furnaces, only one of which is run at a time, owing to scarcity of ore; and the blowing-machinery, which was intended for two furnaces, works therefore well within its power. The blower is a No. 5 Baker, driven by a 15-HP. engine, another 12-HP. engine driving a 10-inch by 7-inch

stone-breaker; whilst a 35-HP. multitubular boiler supplies steam to both engines and to a Blake horizontal tank pump (6-inch plunger, 12-inch stroke), which raises the feed-water for the jackets to two wooden tanks of 10 feet diameter by 7 feet deep, situated at about 6 feet above the top of the jackets. As one-half of the ore from the mines has been already broken in sorting to a convenient size, the stone-breaker only runs for a few hours each day. The jacket takes about 1,200 U.S. gallons of water per hour when running steadily; the water-supply being derived from a well 150 feet deep, situated about 1 mile away. The pump is of the Blake vertical type (7-inch plunger, 18-inch stroke). Water thus raised is such an expensive item that it is necessary to use it over and over again; and the hot water from the jackets is, therefore, allowed to run into 2 cooling-tanks, each 40 feet by 20 feet by 2 feet, where it cools for 2 hours before being passed into a large storage tank 40 feet by 40 feet by 10 feet, at a lower level; being further cooled to about 100° F. by spraying. From this tank the "tank-pump" raises the water again to the wooden tanks as required by the jackets. In this way about three-fourths of the water is recovered, the remainder being lost by evaporation and leakage.

The consumption of fuel is about 2 cords per day of dry mountain oak, which lasts well and gives a hot flame, proving itself equal to about 1½ ton of ordinary Western coal, over which —besides being somewhat cheaper—it offers the advantage of giving better results with inferior stokers; no small consideration in a country where it is difficult to find employees who are not both lazy and careless. The coke used is of the ordinary Western kind, friable and ashy, but it is on the whole cheaper than any better kind would be. Charcoal would be mixed with the coke but for its scarcity and high price, while experiments with coal have not proved encouraging.

The Torreon ores are fortunately docile, containing considerable quantities of ferrous oxide and lime, and rarely need any flux; while, with care in selection, they can be made to stand a slight addition of other ores carrying silica in excess. As a rule, two classes are produced from the mines, the general average of the first class over a long period being 13·05 per cent. of copper and 14 ozs. of silver per ton of 2,000 lbs.; while the general average of the second class is 5·3 per cent. of copper and 4 ozs. of silver per ton; the proportions of each kind used in the furnace varying according to the quantities available. Sometimes very little first-class ore is obtained; and, on one occasion, second-class ore

averaging only 5·06 per cent. of copper was smelted for 31 consecutive days, the slag produced being that quoted in line B, Table II, Appendix, but the yield of "bullion" was in this case very small, causing great trouble in furnace-manipulation, its quantity being insufficient to maintain a proper temperature in the crucible. Whenever obtainable, a small quantity of dry silver ore is always mixed with the ores mined, in order to raise the precious metal contents of the rough pig-copper, which, containing between 96 and 97 per cent. of metallic copper has to be refined in any case by an electrolytic process in order to save the whole of the precious metals. The cost of refining is not less than £7 or £8 per ton, and it is, therefore, advantageous to obtain the bullion as rich as possible. There is, however, great difficulty in procuring ores of silver free from sulphur and lead, and the ores bought always contain some of both elements, so that they must be used rather sparingly, in order not to injure the quality of the pig-copper and increase the production of matte. When the lead present does not exceed 2 per cent. or 3 per cent. of the whole charge, it can be nearly all volatilized; and the quantity of silver ores employed is graduated so as to secure this result. Table II, Appendix, shows the average of twenty-four hours' work of a 36-inch furnace at Torreon under the following circumstances:—

A. When smelting a normal proportion of first-class and second-class copper ores without any silver ores from outside sources. B. When smelting poor siliceous second-class ore alone. C. When smelting ordinary first-class and second-class ores together with a small admixture of silver ores. It will be understood that the figures given under these headings do not represent in any way selected results of special days, nor do they exhibit the maximum capacity of the furnace under favourable conditions; but they are strictly average results obtained during periods of a month or more. Under D and E are given the results of experiments in silver-extraction conducted by the Author, and lasting only 2 or 3 days. The only silver ores nearly free from sulphur and lead available in the neighbourhood were: 1. A highly siliceous ore, consisting of about 75 per cent. of quartz, carrying spots of galena and blende with silver as chloride and sulphide—the average assay showing 2·4 per cent. of lead and 28½ ozs. of silver per ton. 2. Some barytic and quartzose fine ores averaging 5 per cent. of lead and 15 ozs. of silver per ton, with about 50 per cent. of barium sulphate, the remainder being quartz and ferrous oxide.

13 tons of the former and 5 tons of the latter ore were mixed with 10 tons of argentiferous iron-ore, containing 2 per cent. of lead and 2 ozs. of silver per ton. 12 tons of limestone broken to egg-size were added as flux, besides 6 tons of high-grade first-class copper ore carrying a little lead, with the object of ensuring more perfect collection of the silver.

The composition of this "silver mixture" was, therefore, as follows:—

	Assay Results.			Total Contents.		
	Pb.	Cu.	Ag.	Pb.	Cu.	Ag.
	Per cent.	Per cent.	Ozs.	Units.	Units.	Ozs.
13 tons siliceous ore	2·4	trace	28·5	31·2	..	370½
5 „ barytic fine ore . . .	5·0	..	15·0	25·0	..	75
10 „ iron ore (smalls) . . .	2·0	..	2·0	20·0	..	20
6 „ 1st class copper ore . .	..	20·5	76·0	..	123	456
12 „ limestone	..	..	..	..	..	..
46 „				76·2	123	921½

The average being 1·6 per cent. of lead, 2·6 per cent. of copper, 20·06 ozs. of silver per ton.

The charge was 175 lbs. of this mixture, to 170 lbs. of second-class ore (necessary on account of its excess in iron), and 90 lbs. of ordinary first-class ore; the fuel-charge being 90 lbs. of Coahuila coke containing 19 per cent. of ash; the results, calculated for twenty-four hours, are those given in Table II, Appendix, line D. The great reduction in furnace-capacity observable, was chiefly owing to the fact that about half the "silver mixture" charge consisted of "fine ore," which was an addition to the normal charge; since the ordinary first- and second-class ores, when smelted, carry between 5 and 8 per cent., or as much as the furnace will bear without some reduction in capacity. The blast was also slackened so as to get good reduction, an object fairly well attained, as may be seen from the slag-assay, which is very low for such a degree of concentration as 18 to 1. Altogether, the experiment was most encouraging, except as regards the quality of the pig-copper, which was very inferior, as shown by the following partial analysis:—

	Per cent.
Copper	86·68
Lead	3·06
Bismuth	0·64
Arsenic	3·29
Iron	0·35
Zinc	0·27
Sulphur	1·75
Silver	0·73
Nickel, antimony, gold, oxygen, &c., and a little slag mixed with the sample	3·23
	100·00

Under E, Table II, Appendix, are given the details of another experiment conducted in July 1891, the run being of only three days' duration. The "silver ore" of this run was constituted as follows :—

	Assay Results.			Total Contents.		
	Pb.	Cu.	Ag.	Pb.	Cu.	Ag.
	Per cent.	Per cent.	Ozs.	Units.	Units.	Ozs.
6·8 tons siliceous ore	2·4	0·7	28 5	16·3	4·6	193·8
20·1 „ lead ore	14·0	3·0	22·0	281·0	60·1	442·2
38·8 „ iron flux (fine)	2·0	0·5	2·0	77·0	19·4	77·6
				374·3	84·1	713·6

The average being 5·7 per cent. of lead, 1·3 per cent. of copper, 10·7 ozs. of silver per ton.

The experiment was commenced in a hot furnace which had just finished a run of over 1,000 tons of copper ore, and, although thoroughly scoured by passing slag and iron through for several hours before "blowing out," some 400 lbs. or 500 lbs. of metallic copper, carrying 75 ozs. of silver per ton, remained in the bottom of the crucible, whence it gradually melted out, somewhat vitiating the results. About the same weight of base lead-bullion, carrying 200 ozs. per ton, also remained in the furnace after the experiment, and this prevents the formation of an accurate balance of charge and product; but the results are worthy of careful examination. As might have been expected, the bulk of the lead was volatilized; but a portion managed to reach the crucible, carrying with it most of the precious-metal

contents of the ores; and, although the greater part was re-volatilized owing to the intense heat in the crucible, yet its work had been done, and the precious metals remained in a peculiar alloy of copper and lead, which was tapped every hour to form small pigs of base bullion. The loss of silver in the slag was considerable, amounting to an average of $2\frac{1}{2}$ ozs. per ton; but this is not surprising, considering the extraordinary degree of concentration, nearly 30 to 1. In many cases, the saving in freight &c. on the bullion, effected by this high degree of concentration, would more than compensate for such increased loss of silver in slags. The experiment was not a success from a financial point of view, on account of the low price obtained for this novel kind of base bullion, and the refining-charges were exceedingly heavy on account of the difficulty of thoroughly freeing the copper from the lead and *vice versâ*. No mention has been made of the low gold contents of the ores, but all Torreon pig-copper carries from $\frac{3}{4}$ oz. to 1 oz. per ton, and there can be no doubt that, as in the case of lead-smelting, the extraction of gold is at least as perfect as that of silver—probably somewhat more so.

Attention has already been drawn to the limited scope of this metallic copper-extraction process, caused by the adverse influence exercised by sulphur, lead, and other elements, over the quality of the base bullion product. It also labours under the disadvantage that the $1\frac{1}{4}$ per cent. to $1\frac{1}{2}$ per cent. of copper lost in the slag is far more valuable than the somewhat smaller quantity of lead in lead-slags; each ton of slag from the silver ores and their fluxes carrying away some 20 lbs. or 30 lbs. of copper, worth about $3, compared with a loss of about 75 cents in lead. On the other hand, the degree of concentration found satisfactory with poor ores, say, 18 or 20 to 1, is fully twice as great as that possible on a lead basis, causing a saving in freight sufficient in many cases to more than balance the disadvantage of extra loss in slag. It will be seen that the rate of concentration of copper ore alone reached on one occasion 37 to 1, without raising the loss of silver in the slag, the small quantity of this metal contained in the ore being perfectly concentrated into the resulting bullion product. So far as the Author is aware, no such poor ores have previously been smelted to pig-copper at one operation in a blast-furnace. In regard to the extraction of silver and gold from their ores by the action of metallic copper, although in principle well known to metallurgists, no record has, so far as the Author is aware, been hitherto published; and, possibly, the results here given may induce others to experiment in what is almost a new field.

Cost of Smelting at Torreon.

The cost of smelting depends greatly upon local conditions—price of fuel, rate of wages, &c. Mexican labour, although apparently cheap, is in fact dear, on account of its inefficiency and untrustworthiness. Although barrow-men and shovellers are paid $1 per day (say 3*s.* in English money), it occupies about 5 of them 11 hours to get through the work that two English navvies do in 9 or 10 hours. The wages paid vary from 3*s.* for wheelers, up to 4*s.* 6*d.* for slag-men, and 6*s.* for engine-drivers. On account of the untrustworthiness of native labour, it is found necessary to employ an American foreman on each shift as head tapper, besides a mechanic to look after the engines, pumps, &c., the wages paid to these men being from 15*s.* to 17*s.* 6*d.* per day. Coke, of the inferior kind alluded to, costs about £2 17*s.* 6*d.* per ton of 2,000 lbs., but there is always considerable deficiency in weight and loss in breeze, averaging between 7 and 10 per cent. Coal of inferior quality costs about £2 4*s.* per ton of 2,000 lbs.; and good mountain oak costs about £1 5*s.* per cord, at which price it is slightly cheaper than coal.

The cost of smelting at Torreon at the present time is—

	$	
Labour, including foremen, sampling, &c. . .	1·64	per 2,000 lbs.
Materials, oil, light, tools, repairs and fluxes .	0·35	„
Boiler-fuel, coal and wood	0·45	„
Coke	3·30	„
General superintendence and office expenses .	0·78	„
Total	$6·52	

The above figures have been reduced from the total cost of the last 6,000 tons smelted. If calculated at the average rate of exchange ruling during the past 3 years, the costs in English money are as follows :—

	£	*s.*	*d.*
Total cost of smelting, per ton of ore	1	0	1
Ditto, allowing for slag, &c., smelted	0	18	6

In spite of the small scale of the operations, this compares favourably with the cost at El Paso and at Las Trojes, especially the latter. With the El Paso works it is perhaps hardly fair to attempt a comparison, because the conditions are so different. A comparison with Las Trojes, Michoacan, is easier, because, although a good deal of superintendence is required to guard

against the thievish propensities of Mexican labourers, yet, as the works treat ores from mines belonging to one company only, no such complexity is introduced as in the case of a custom works. The prices of coke and charcoal practically equalize the charges for fuel at the two places. Las Trojes again enjoys the advantage over Torreon of water-power instead of steam-power. On the other hand, the comparatively high percentage of zinc, and the preponderance of fine ore, cause some reduction in furnace-capacity, and otherwise adversely influence the cost of smelting; but, allowing for all disadvantages, it would seem that considerable economy might be effected by reorganization of the arrangements. As the Las Trojes ores are so poor in lead, the right treatment would appear to involve considering matte rather than lead as the important vehicle for extracting the silver in the first instance; modifying the furnaces so as to adapt them to the matting-process, and making the subsequent treatment of the roasted matte entirely independent of the ore-furnaces.

These remarks lead to the consideration of matte-smelting; a subject which is already of considerable interest, and one that is destined to become of still greater importance in the course of the next 10 years. With this the Author hopes to be able to deal at some future time. No reference has been made to refining-processes, because the subject is quite distinct from that of extraction of metal from ores. Refining is frequently carried out in establishments quite distinct in ownership from the smelting-works, and, even when belonging to the same company, the administration must be independent.

The Paper is accompanied by five sheets of tracings, which have been used for the preparation of Plate 3.

APPENDIX.

TABLE I.—COMPARISON OF SMELTING-WORKS AT EL PASO, TEXAS, WITH THOSE AT LAS TROJES, MICHOACAN, MEXICO.

—	El Paso, Texas.	Las Trojes, Mexico.
1. Motive-power for blowing and general purposes	Two steam-engines of 100 HP. and 125 HP. nom. One running, one in reserve	6 feet Pelton wheel, 500 feet head of water, 2 engines in reserve.
2. Number of furnaces	8	2
Dimensions at the tuyeres	120 inches by 42 inches.	84 inches by 33 inches.
Material of jackets	Cast-iron.	Wrought-iron.
3. Number, size and pattern of blowers in use and in reserve respectively	*In use* 1 Baker No. 7½ 1 „ 5½. 1 „ 4½. 1 Root No. 7. *Reserve* 1 Baker, No. 7½.	*In use* 4 Baker, No. 5. *Reserve* 2 Baker, No. 5.
4. Height of furnaces from tuyeres to charging-floor	17 feet.	13 feet.
5. Number of tuyeres per furnace	13	10
Diameter of tuyeres	4 inches.	5 inches.
6. Average head of blast	17 inches water.	16 inches water.
7. Consumption of water per hour	4,000 U.S. gallons (= 3,200 imp. gallons).	
8. Composition of charge—		
Ore	900 lbs.	480 lbs.
Limestone-flux	350 „	20 „
Slag	300 „	400 „
Roasted matte	..	180 „
Litharge	..	120 „
Total	1,550 „	1,200 „
9. Composition of fuel-charge	Coke, 200 lbs.	Coke, 75 lbs.
„ „	Charcoal, 40 lbs.	Charcoal, 75 lbs.
10. Average amount of charge put through per furnace per 24 hours	Ore 40½ tons. Flux, 15½ „ Slag, 13½ „	Ore, 36 tons. Flux, 1½ „ Slag, 30 „ Matte, 13½ „ Litharge, 9 „
Total	69½ „	Total . 90 „

TABLE I.—COMPARISON OF SMELTING-WORKS AT EL PASO, TEXAS, WITH THOSE AT LAS TROJES, MICHOACAN, MEXICO—*continued.*

——	El Paso, Texas.	Las Trojes, Mexico.
11. Average assay of ore-charge in lead and silver	Lead, 11 to 13 per cent. Silver, 40 ozs. per ton.	Lead, 3 per cent. Silver, 28 ozs. per ton.
12. Average production of bullion per furnace per 24 hours	4 tons.	8 tons.
13. Average assay of bullion in silver and gold	Silver, 200 to 300 ozs. Gold, ½ to 1½ oz.	Silver, 120 ozs. Gold, traces.
14. Average production of matte per furnace per 24 hours	1½ ton.	7½ tons.
15. Average assay of matte in silver	80 to 100 ozs.	16 ozs.
16. Average amount of flue-dust produced	3 per cent. of ore.	Not saved (at present).
17. Average assay of flue-dust	Lead, 15 to 20 per cent. Silver, 30 to 40 „	Not known.
18. Average assay of slag	Lead, ½ to 1½ per cent. Silver, ¾ to 1½ oz.	Lead, 0·8 per cent. Silver, 1½ oz. per ton.
19. Approximate composition of slag produced	Per cent. SiO_2, 32 FeO, 38 CaO, 20 Oxides of zinc, lead, aluminium, sulphur, &c. 10 100	Per cent. SiO_2, 25 FeO, 40 Al_2O_3, 7 CaO 9 PbO, 1 ZnO, 10 S, 8 100
20. Price of coke delivered at the works per ton of 2,000 lbs.	£1 15*s.* 0*d.*	£3 4*s.* 4*d.*
21. Price of charcoal delivered per ton of 2,000 lbs.	£2 10*s.* 0*d.*	£1 8*s.* 0*d.*
22. Average number of men employed and daily wages paid	Americans, 150 at $2.25 to $3 per day. Mexicans, 250 at $1 to $1.75 per day.	..
23. Total cost of smelting per ton of ore	£1 9*s.* 9*d.*	£1 10*s.* 8*d.*
24. Cost per ton of charge, including flux and slag, but not matte, litharge, &c.	£1 2*s.* 7*d.*	£0 16*s.* 5*d.*

TABLE II.

	Ore smelted.				Coke used.	Ore per Ton of Coke.	Slag re-smelted.	Charge per Ton of Coke.	Product.			Assay Results.											Average Blast.		Supposed Weight of Slag Produced.
												Ore.			Copper.			Matte.			Slag.				
	First Class.	Second Class.	Silver Ore.	Total.					Bullion.	Matte.	Total.	Copper.	Lead.	Silver per ton.	Copper.	Lead.	Silver per ton.	Copper.	Lead.	Silver per ton.	Copper.	Lead.	Silver per ton.	Revolutions of Blower.	Pressure.	
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Lbs.	Lbs.	Lbs.	Per Cent.	Per Cent.	Ozs.	Per Cent.	Per Cent.	Ozs.	Per Cent.	Per Cent.	Ozs.	Per Cent.	Per Cent.	Ozs.	No.	Ozs. per Sq. In.	Tons
A .	6·6	34·9	..	41·5	7·4	5·6	3·4	6·0	4,457	145	4,602	6·56	..	4·5	96·7	..	75	78	..	36	1·48	..	0·5	72	7	34
B .	..	42·7	..	42·7	7·2	5·7	2·7	6·3	2,196	573	2,769	5·06	..	2·9	96·5	..	89	76	..	38	1·78	..	0·5	78	11	38
C .	8·6	30·2	2·2	41·0	7·8	5·3	4·3	5·8	4,611	206	4,817	6·77	tr.	6·7	95·7	tr.	107	77	..	50	1·46	..	0·75	75	8	32
D .	5·9	11·2	11·4	28·5	5·9	4·8	2·5	5·25	2,814	342	3,156	5·83	0·6	12·5	86·6	3·06	210[1]	77	tr.	166	1·65	tr.	1·7	68	10	22
E .	2·3	..	19·7	22·0	4·6	4·8	2·5	5·3	1,213	346	1,559	1·3	5·7	10·7	50·7	32	235[2]	37	26	193	1·2	1·4	2·5	60	11	19

[1] This bullion carried $\frac{8}{10}$ oz. gold per ton.

[2] This bullion carried $1\frac{2}{10}$ oz. gold per ton.

The figures given as silver ore include necessary fluxes for the siliceous portions.
The ton used is the U.S. short ton of 2,000 lbs. avoirdupois.

(Paper No. 2583.)

"The Erection of Silver-Lead Smelting-Works in Mexico."

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The development of the mineral resources of Mexico during recent years, aided by the reductions in the price of coke owing to the extension of railways there, has led to the erection, in various parts of the Republic, of furnaces of the most modern type. The Author proposes to describe in detail the erection of a silver-lead smelting-plant, capable of treating 100 tons of ore daily, with provision for future extension, for the Michoacan Railway and Mining Company, of London, at Las Trojes in the State of Michoacan, Mexico, situated at an altitude of some 9,000 feet.

The general plan of the new works is shown in Fig. 1, Plate 4. An old slag-tip was converted into a charging-floor for the new works; the furnaces were erected on a lower level beyond the edge of the tip, the charging-doors being level with its surface; and on the same level were erected the blowers, engines, boilers, and general machinery. An outer retaining-wall was first built, running along the front of the works, as shown in Figs. 2, 3, and 4. It was founded on a soft porphyritic rock, and was only needed temporarily, as the running of the new furnaces would rapidly bury it altogether in slag. As this wall was erected, the filling behind it was simultaneously carried up to the level of the intended furnace-floor. During the erection of the new works, the old furnaces were running continuously, and these supplied some 40 tons of slag daily. In the ordinary course of working, the balls of slag from the slag-pots were placed at the edge of the old tip, and broken to pass through a 5-inch gauge-ring in order to separate any matte, speiss, or lead that they might contain; this slag was then further reduced in size until small enough to pass a 3-inch ring, and was used as filling. Soft stone was also obtained from the adjacent hill-side for the same purpose. Under the water-motor and engines, the filling was broken to pass through a 2-inch ring, and thoroughly rammed. The entire area was filled in layers, the smaller-sized filling under the foundations being always kept some 2 feet above the main portion until the level for the bottom of the foundation-blocks was reached, when the masonry was carried upwards in the same manner. Stone for

masonry was obtained from the bed of an adjoining stream, where there were many boulders of porphyry, rarely, however, exceeding 2 cubic yards in content. This porphyry was hard, durable, and well adapted for rubble masonry. It was all broken with dynamite. The larger stones which were required for the foundations of the furnaces, were plugged and feathered in the usual way.

When the filling was nearing completion, a series of bench-marks were fixed on the area, and some charges of dynamite were exploded without any subsidence being observed. Under each engine a block of masonry was carried up from a depth of 9 feet, with a horizontal section of 186 square feet—thus containing about 110 tons of masonry. A block of 840 cubic feet of masonry was also built under the Pelton water-motor which drives the machinery. These large masses of masonry were put in because there was much doubt felt as to the stability of the slag-filling under the vibration of the machinery. The foundation-blocks under the furnaces are 5 feet thick, and on these, immediately under the cast-iron columns, Fig. 5, large stones were placed running well under the main structure. The weight of each furnace with its burden is equal to 1½ ton per square foot, which, however, as will be seen on reference to the figure, is taken up to a considerable extent by the four columns at the corners. The furnaces were supplied by Messrs. Fraser and Chalmers, of Chicago, and are of the water-jacketed rectangular type, each having, with the class of ore smelted at Las Trojes, an actual capacity of 90 tons of charge per 24 hours, not including fuel. Fig. 5 illustrates the furnace; its principal dimensions are: section at the tuyeres, 36 inches by 84 inches, in the shaft of the furnace, 66 inches by 84 inches, in the stack, 42 inches by 42 inches; from the centre of the tuyeres to the charging-floor, 12 feet 6 inches; from the tuyeres to surface of lead in the well, 11 inches. The lead-well is 21 inches deep and holds 6½ tons of lead, which is tapped by an inverted siphon. The well has ¼-inch wrought-iron plates covering the sides and bottom, to prevent the soaking of lead into the foundations. The water-jackets, Fig. 6, are of wrought-iron, and extend from 2 feet 10 inches above the tuyeres to 10 inches below them. The bottom of the smaller or end jackets extend down only to 2½ inches above the tuyeres. The thickness of the inside plate of the jacket is ⅜ inch, that of the outside plate $\frac{5}{16}$ inch, and the water-space between them is 6 inches. The side and end jackets are bolted together by ¾-inch bolts and angle-plates. In the longer jackets, water enters at two points by pipes,

as shown in Fig. 6; the water is delivered well down in the jacket, and, entering at a lower temperature than that surrounding it, immediately sinks, thus causing good circulation. The hotter discharged water is taken off at the top and runs away through a gutter, shown in the figure.

In the rainy season in Mexico, the water is often heavily charged with organic and earthy matters in suspension. At such times, care should be taken to strain the water in some simple manner before it enters the jackets. Some jackets are also provided at the mud-hole with a gland and rod to which is attached a scraper or agitator, which can be drawn in and out so as to stir up any sediment that may have been deposited. (The Author has known a case of a smelter where, during heavy rain, the water-pipes and channels leading to the jackets were completely filled with stones, and the jackets had to be supplied by hand.)

The furnace has, at each side, five 3-inch tuyeres of the Devereaux type, 16 inches apart. By the use of this tuyere the inclination of the blast may be varied at will, and air can readily be shut off from any desired tuyere by a hand-valve. They are objectionable inasmuch as the furnace-man is at some distance from the furnace-contents, and, although movable, it is inconvenient to remove them on account of their weight; they are provided with mica eye-plates to allow of the furnace being watched. In working the furnace, the slag forms a skin on the jackets which effectually prevents any leakage of slag between them, and also tends to prevent undue chilling at the smelting-zone. The blast is supplied by the 3-feet main air-pipe, Fig. 2, leading from the blowers, and is carried round the jacket by a 15-inch galvanized-iron pipe. A specially woven 6-inch flexible pipe brings the air from this pipe to the tuyeres. The usual pressure of the air supplied is 17 inches head of water, or about 10 ozs. per square inch, but the furnace is adapted to much higher pressure. It is difficult, however, to form even an approximate idea as to the quantity of air supplied. The furnace is built with fire-bricks up to the level of the charging-door, and above this with ordinary bricks. A 3-feet wrought-iron down-take, Figs. 2, 4, and 5, carries the dust and fume to the main furnace-flue, and the furnace can be worked into this or not as desired. The main furnace-flue is 7 feet broad and 10 feet in height; it has an inclined brick bottom, and all deposits can readily be scraped out through the cast-iron doors shown in Fig. 4. This flue connects with the long flue running under the charging-floor, which it is ultimately intended to carry up the hill to a height of 350 feet. The flue is 6 feet by 8 feet in cross-

section. At the present time it terminates at the foot of the hill, and is surmounted by a temporary chimney.

In the design of the works, a large space is devoted to the erection of reverberatory furnaces, with provision also for extension. The furnaces are to be 74 feet in length, the roasting-hearth being 13 feet wide, and the fusion-hearth 11 feet long by 11 feet wide. The capacity of each furnace will be 5 tons of fine sulphide-ores roasted per 24 hours; and on the fusion-hearth some 8 or 9 tons of fine ore can be fritted together in the same time. There is, in the mines of the company, a large amount of fine ore, which needs to be treated in reverberatory furnaces and fritted together, to render it suitable for charging into the smelting-furnace, raw or roasted fine ore having a tendency to choke the furnace and lower the rate of driving. The reverberatory furnaces will discharge their smoke and fume into a flue shown in Fig. 1, connected with the main flue on the hillside. The furnaces are to be charged through hoppers, and a platform will run behind them, on which the supply of ore will be laid down.

The machine- and engine-house has several exceptional features. The line of shafting running down the centre of the shop is 4 inches in diameter and 3 feet above the floor; it is driven as required by either the Pelton wheel or by the engines at each end. The engines are coupled directly on to the shaft by clutch-couplings. They are non-condensing, and originally formed part of the old plant. They are intended to be held in reserve only, as a good supply of water is expected all the year round.

The Pelton wheel, Fig. 7, is 6 feet in diameter, and is supplied with water by a 12-inch wrought-iron pipe, from a tank at the end of the launder, 487 feet above the level of the nozzle. The 12-inch pipe-line is carried across the charging-floor, by a light trestle, at a height of 25 feet above ground-level, until it strikes the hill, after which it runs along the slope. The launder, which is built entirely of wood, is 7,462 feet long, having a sectional area of 4 square feet, and an inclination of 1 in 1000. Its maximum capacity is 350 cubic feet of water per minute—delivered at the wheel through a nozzle $2\frac{1}{2}$ inches in diameter. When the water in the launder is only 1 foot in depth, 150 cubic feet of water are delivered through a $1\frac{3}{8}$-inch nozzle. The water available at the end of the dry season is never less than 150 cubic feet per minute; but, during the rest of the year, there is much more. The launder, running full, develops at the Pelton wheel 253 HP., and, running half-full, develops 108 HP. These powers are based on an efficiency of 80 per cent., guaranteed by the

Pelton Company; but the actual horse-power is probably higher. The tail-race from the wheel passes to the race of the turbine of the old works. It is 2 feet square in cross-section, and has an inclination of 1 in 100. The water from the water-jackets and the elevator is also discharged into this channel. Owing to the head of water, the boilers can be fed direct from the stand-pipe, the pressure of the steam in the boilers being 100 lbs. per square inch, and that of the water 207 lbs. per square inch; the "elevator," described below, is also actuated in the same manner. All these branch-pipes are connected, by a 6-inch Ludlow stop-valve, with the main 12-inch pipe-line. The Pelton wheel appears to be well adapted for use in districts where small quantities of water under considerable pressure are available. The best speed for the wheel is attained when the circumferential velocity is one-half that of the impinging jet of water—270 revolutions per minute at Las Trojes.

The blowers, arranged as shown in Fig. 2, are of the Baker type, and each one supplies 30 cubic feet of air at atmospheric pressure per revolution; all deliver directly into the 3-feet air-main. This main is made of $\frac{1}{8}$-inch wrought-iron plate, with $\frac{5}{8}$-inch cast-iron flanges, jointed with india-rubber washers. It has a relief-valve, in case of increase of pressure owing to any sudden drop in the furnace-charge. The main is led through the entire length of the machine-room, and out behind the furnaces. The main in the old works was below ground, but much difficulty was experienced owing to leakage and fracture, caused by the passage of vehicles over it. Under the blowers is a brick channel 3 feet wide by 4 feet deep, which projects 6 feet beyond the outside of the machine-building, its object being to prevent excessive aerial vibration in the house, and to ensure a good supply of air. The blowers are fastened to heavy 14-inch by 12-inch beams, which are bolted down to the brick-work. According to the makers, 17 HP. ought to be allowed for each blower. They are designed to run at 125 revolutions per minute, and three blowers are sufficient to supply two furnaces. The elevator between the machine- and furnace-buildings is for raising the silver-lead and matte produced, to the level of the charging-floor. The table is 8 feet by 6 feet, and has a lift of 16 feet. The ram is direct-acting, and is $10\frac{1}{2}$ inches in diameter, and $\frac{1}{4}$ inch thick. The water is admitted to the ram by a three-way rack-valve. From the charging-floor, railway-branches connect with the Ferrocarril Michoacan y Pacifico, which joins the Mexican National Railroad at Maravatio.

The ore treated in the furnaces described, is of a character not

generally considered suitable for smelting operations, being poor in lead. Indeed, the ore had for many years been treated altogether by amalgamation processes, until, as the mines were worked deeper, sulphides and leady ores were encountered, rendering amalgamation so expensive that it was finally abandoned. Even at the present time, lixiviation, after a preliminary separation of the leady portions, has been proposed by metallurgists who have reported on the ores of the district. The silver probably exists in the ore as sulphide and arsenide, finely disseminated through the various minerals composing it; attempts at silver-concentration have, up to the present, invariably proved a failure. On crushing and concentrating the ores from as much as 8 parts to 1, it has rarely been found that the concentrates contain double the percentage of silver in the original ore pile. The class of ores extracted differs widely in the various mines of the company, and, as received at the smelting works, their composition usually varies within the following limits:—

Lead	traces
Iron	10 per cent. to 30 per cent.
Zinc	2 „ 12 „
Antimony	traces
Copper	traces
Sulphur	18 per cent. to 25 per cent.
Silica	15 „ 30 „
Alumina	traces
Lime	traces

Ore carrying less than 28 ozs. per ton of silver, is not considered worth mining.

At present the ore is burned in heaps, and, in consequence of the amount of zinc present, a certain quantity of silver is lost in this operation. The burnt ore contains between 5 per cent. and 8 per cent. of sulphur. A typical mixture for smelting consists of—

Roasted ore	40 per cent.
Litharge	8 per cent. to 10 per cent.
Roasted matte	10 „
Slag	35 „
Lime	5 „

The litharge is produced by refining the silver-lead in German cupellation-hearths on the works. The lime is brought some 3 leagues by mules, and costs 19*s.* 6*d.* per ton delivered at the works. The mixture contains between 15 ozs. and 20 ozs. of silver per ton, between 2 per cent. and 8 per cent. of zinc, and 12 per cent. of lead.

A furnace-charge is 600 lbs., and takes 80 lbs. of fuel. The fuel is partly Connellsville coke, and partly charcoal—31 per cent. of the former, and 69 per cent. of the latter. The coke costs on the works £3 2*s.* per ton. The charcoal costs £1 1*s.* 7*d.* per ton; but it is of a very inferior description, and only some 50 per cent. to 70 per cent. of it is serviceable; it is burnt by Indians in the Company's forests, and is principally obtained from pine-wood, although a small amount of oak is found. The products of the furnaces are:—

(1) A silver-lead alloy termed "base bullion," containing 75 per cent. of the silver in the original charge; this alloy contains 0·4 per cent. of silver. (2) An iron matte with 20 per cent. of the silver in the original charge; it usually carries about 20 ozs. of silver to the ton; it is piled in heaps and burned—burning freely; and is then re-passed through the furnace. (3) A slag containing the remaining 5 per cent. of the silver in the original charge. This slag carries between 1 oz. and 1½ oz. of silver per ton, and is a waste product. If at any time it is found to be too rich, it is used as required to make up the smelting-charge. The cost of smelting a ton of ore is between £1 17*s.* and £2 6*s.* The cost of smelting a ton of mixture is about 16*s.*; these prices include roasting the ores, and refining the "base bullion."

The problem of smelting in the Republic of Mexico, is unlike that in Europe or the United States, being affected by the circumstance that the labourers are apathetic in temperament, and physically incapable of continuous toil. For this reason, there is a tendency, in Mexico, to look with greater favour on 30-ton or 40-ton furnaces, as they do not require such heavy manual labour, and are managed and kept in order much more easily than those of larger size. These furnaces are generally round in section, with 5 water-jackets; one having a hinge at its upper portion, to facilitate cleaning out the zinc shell that has a tendency to form in all these furnaces with the class of ore met with at Las Trojes. These furnaces vary between 36 inches and 42 inches in diameter—the last dimension being, perhaps, a maximum; 36 inches at the tuyeres is usually found a satisfactory size; the larger sizes being only recommended where very little fine ore is smelted, and where good English coke is used. In the furnaces at Las Trojes, there are two charging-doors to each—the charge being shovelled in alternately from either side. A 4-feet by 7-feet iron plate, running smoothly into the furnace, is laid at the doors to aid in the handling of the charge. A rim, some 6 or 8 inches high at the door, is recommended, so that the ore must be lifted

and thrown in, in order to ensure a better distribution of the material. In smelters where sulphides are treated, the ore is roasted before entering the furnace. In Mexico this operation is almost invariably conducted by open-air burning in heaps, generally on the works. In the selection of a site for the roasting, care must be taken that the sulphurous fumes may not descend on to the charging floors, as much inconvenience is caused thereby. An inverted funnel-shaped apron should be affixed over the slag-tapping holes, and connected by pipes to a point above the main building, in order to prevent the smoke from hanging about where the men are working. By this means the disease known as "leading" may be entirely avoided, and the general health and comfort of the workmen ensured.

The Paper is accompanied by 2 tracings from which Plate 4 has been prepared.

[Discussion.

Discussion.

The President. The PRESIDENT said the profession of civil engineering embraced a great variety of branches, and it was the desire of those who directed the business of the Institution that each branch should receive attention in the Papers that were read and discussed. Thus, the first Paper of the Session was on Graving Docks, and no fewer than four different kinds of such docks were described—a subject interesting to those who, like many of the members, carried out public works. The next Paper dealt with the Construction of Small Arms, a very important subject, interesting particularly perhaps to mechanical engineers, but generally to the country at large. The third Paper read was on Gas Power for Electric Lighting—a subject of interest to electrical engineers, gas engineers, and mechanicians. The Papers on Smelting Processes, now before the meeting, were of interest to all members, but especially to mining engineers, metallurgists, and to those who studied chemistry as a branch of their profession. In that way, already six or seven different branches of the profession had been represented, and the Session was not yet one-half over; so that it would be seen that the intention of the Council was being satisfactorily carried out. He was sure it would be the pleasure of members to thank the Authors of the Papers now under consideration for the good service they had rendered to the Institution in bringing forward the result of their experience in those important processes.

Mr. Bayliss. Mr. R. T. BAYLISS had heard the Papers with great interest, containing as they did a most able explanation of the modern practice of smelting silver and gold in the United States. He would suggest that the Author of the first Paper, in estimating the average saving of silver and gold at 92 per cent., was putting it a little lower than the average practice in the United States. As a matter of fact, smelters generally paid for 95 per cent. of the silver and full value for the gold contained in ore, and he hardly thought they would do so if they only succeeded in recovering about 92 per cent.

Mr. Rickard. Mr. THOMAS RICKARD observed that there had been a conspicuous omission in the Papers in respect of the collection of fumes. The fumes had been treated as if they were almost of no consequence. They were of course somewhat unimportant when dealing with

silver, gold, and copper; but when dealing with lead they were of the utmost importance. The fact was, in lead-smelting at the present day, something like 13 per cent. had been shown to be capable of collection by means of condensation in galleries, chimneys, or flues carried away from the head of the furnaces. There were cases where that was done, *e.g.*, at Pontgibaud, in France, where ores were taken past the smelting-works on the sea-board, brought more than 100 miles inland, part of the distance by cart, the fuel was carried in the same direction, and the lead was sent back in competition with smelters who were almost in the midst of the coal-fields. In dealing with the furnaces at Torreon, he thought too much had been devoted to the mechanical construction of the works and the water-jacket. It was customary nowadays to lay a good deal of stress upon the water-jacket, which was, however, merely a necessary evil. A furnace protected by means of water sacrificed a material part of its heat in order to save its lining. It was much better, where possible, to bring the materials into such a condition by previous treatment that the water-jacket could be dispensed with. Again, the tendency towards exaggerated quantities per day was an evil justifiable only by the exigencies of certain local conditions. For instance, the best smelting of fallow ores was perhaps that done in Sweden and Russia, particularly in the great Permian district, where, dealing with copper ore containing only about 2½ per cent. to 4 per cent. of copper, the slag contained only about 0·25 per cent. He doubted whether anything of the sort had been approached in America. Then, again, there was a tendency to dispense with what was of equal importance with hearth-smelting, viz., the preparation by calcination. That had never been better carried than in the works at Argo, Denver, and at Pontgibaud in France. At the latter place the process was so efficiently carried out by stall- and furnace-roasting that an air-blast of only 4 inches of water sufficed, whereas in the case referred to by the Author, the pressure often exceeded 20 inches. With a high blast there was a corresponding loss of lead by volatilisation. The Americans were endeavouring to do for England, what England had long ago done for Germany and France in iron smelting; but it was certain that, as railway communication increased, and the price of labour decreased, so they would revert to the old methods. There was nothing so perfect in smelting in America as there was in Europe; and if the handicap placed upon English production by extravagant import duty were taken away Englishmen could still manage to hold their own. The display of constructions of

Mr. Rickard.

Mr. Rickard. the kind shown in the Papers would give no proper impression of the relative merits of smelting processes. It was known that the furnaces yielded, under favourable conditions, more than the assay value of the silver. He knew of cases where silver and lead were smelted in such a way that there was an excess of 3 to 4 per cent. of silver over the total assayed contents of the ore purchased; and in purchasing nowadays, it was in competition with sworn assayers, who did not allow a margin of anything like 4 per cent. or $\frac{1}{4}$ of $\frac{1}{10}$ per cent. on the silver, and that was about as safe an indication as could be given of the perfection of the work. This was done with labour at about 4*s*. per day, at a total cost of 36*s*. per ton. It seemed to him that the Author overstepped the mark in claiming any merit for a system of smelting which lost 25 per cent. of its metal. If that were to be the future of smelting, the sooner it was unlearnt the better. He did not desire to appear prejudiced in the matter. All these things depended greatly upon local circumstances, and it was rather unfair to criticise them on that account. They could be criticised only on general principles, particularly as the tendency with regard to smelting was to exaggerate mechanical arrangements at the expense of good smelting principles. With regard to lead colic, he had found that by using ordinary precautions at the refinery and at the desilverization, and in collecting the fumes, the men could be kept clear of colic by using a little sulphuric acid in the water they drank. It had been found at the Pontgibaud works, that, by the use of a ventilator of sufficient displacement to take the whole of the fumes through a spray of water, much more of the fumes could be collected than they could by the dry method with large extent of flues. Further, by giving the flues an appropriate inclination, the fumes were brought out by water into large reservoirs and were allowed to consolidate, and in that condition they were taken back to the furnaces and very conveniently handled. With regard to the water-jacket, the claims put forth for the water-jacketed furnace meant nothing. In the first place it might be simply a modified Castillian furnace, or it might be a modified Pilz furnace, or it might be, as it often was, a modified Rachette furnace. It was as applicable in the one case as in the other. Really the term "water-jacketed" was a misnomer, and should be avoided.

Mr. Louis. Mr. Henry Louis was glad of the opportunity, not so much of criticising an established process, without which many of the valuable silver and gold ores of North America could not possibly have been worked, as of asking a few questions for infor-

mation. His experience of smelting precious metals dated a good many years back, and was confined simply to calcining and matting in reverberatory furnaces; and he had no personal knowledge of the process described by the Author. In the first place he wished to understand how the loss had been calculated? 92 to 95 per cent. seemed an enormous quantity of precious metal to extract, if calculated upon raw ore that had to be calcined. In calcining, say, the telluride ores of California, the losses even in gold were heavier than from 5 to 8 per cent., and in calcining silver ores, especially where zinc was present, they were often much higher. As far as he could understand from the diagrams, he could not see that any provision had been made to catch the gold and silver that would be lost in the calcination process only. As to the losses that would probably ensue in the smelting-furnace, he was not competent to speak; but, in reference to probable losses in the fume, he would ask whether the well-established method in iron-smelting, of closing the furnace top with a bell had ever been attempted, and, if so, with what result? He would also ask if any attempt had ever been made to apply the smelting process to the concentrates from gold mills? Seeing that gold mills generally produced concentrates consisting of iron and arsenical pyrites, which were often rich in gold, it would seem that the calcination of these pyrites, either with or without previous matting, would give an auriferous oxide of iron which would form the very flux wanted in smelting siliceous lead ores. He would be glad to know whether any work in that direction had been done; also whether the copper-jackets used in the Lake Superior district in smelting copper ores had ever been applied in the copper concentration process alluded to in the Papers. Mr. Louis.

Mr. William Semmons observed that it was important to notice that in the large works conducted at Argo in Colorado, for smelting silver-copper ores, the water-jacketed furnace was not used, but the old style of reverberatory furnace was applied, and in that particular instance, modification in the arrangement of the bars had given marvellous results in economy. It had been shown by Mr. R. Pearce,[1] the manager of those works, that there had been derived from the old Swansea furnace more than twice the work obtained during the time that the reverberatory furnace had been used by him about 20 years ago. Mr. Semmons endorsed the statement made by a previous speaker that the water-jacketed Mr. Semmons.

[1] Transactions of the American Institute of Mining Engineers, vol. xviii. (1889), pp. 52–72.

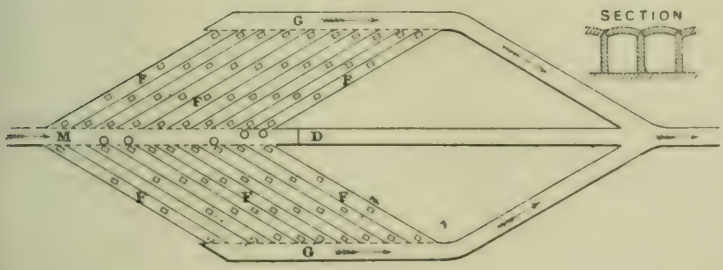
Mr. Semmons. furnace was the result of efforts to get over a great evil. When it was first established in Arizona, the cost of fire-brick, which had been stated in the Paper to be *5d.*, was then *5s.*; so that one could imagine the very great difficulty of constructing an ordinary reverberatory furnace. And not only was the cost of the brick so high, but the material had to be carted 800 miles to the nearest station. He would mention the difficulties under which some of these operations were conducted. In Mexico, the works referred to were at an altitude of 9,000 feet above the sea-level. At the large works at Denver, the heat was so intense during the summer that they were obliged to have large cakes of ice and play water on them, in order to cool and make the air bearable to the men. He thought if the water-jacket were of so great advantage over the ordinary old method of smelting, it would by this time have been adopted by some of the English smelters.

Mr. Cowper. Mr. E. A. Cowper was sure the Institution was much indebted to the Authors for the communication of Papers of so practical a character. The first Paper showed how, under certain circumstances, it was well worth while to ignore any value there might be in a small portion of zinc, antimony, bismuth, arsenic, &c., in the ores treated, in order to smelt as much lead, gold, and silver as possible with a given amount of expensive fuel and labour. The careful proportioning of the various ores in order to obtain a "burden" that would smelt well was most instructive. That was done to some extent in iron-smelting, but then there was generally a particular ore or ironstone in great preponderance, so that it was absolutely necessary to pay most attention to the proper smelting of such material with lime enough to make a clean slag. Sometimes a small quantity of aluminous ore was added to such rich ore as hæmatite, merely to keep the furnace open. He wished to notice two points; the first a small one, and the second of more importance. In taking samples of any loose dry material, it was not sufficient, in order to thoroughly mix it, to pass it through a sieve having a circular motion, as then small lots were only distributed in circles, and any one small rich lot, or different kind, would only make one circle in the midst of the mass; but if it were passed through one sieve moving in a straight line, a spot became a line at once; and then, if another sieve below the first moved in a straight line at right angles to the first, that line became a plane, so that every small lot of material was distributed over the whole surface. The second point that he wished to refer to, was the saving of "fume" from such furnaces as those described in the Papers, or from lead or from Scotch furnaces.

Mr. Cowper.

The plan resorted to in the works described, followed the common old-fashioned idea of a long flue from the furnaces to the stack, and sometimes combined with chambers. That was a mistake, even if the flue were very long (it was sometimes ¾ mile in length), for the draught through the flue kept by far the greater part of the fume in motion, and carried it out at the top of the stack; but if, on the contrary, there was but a slight draught and the fume and gases moved along very slowly, say, at one-twentieth the speed in an ordinary flue, the fume would deposit in large quantity. The plan might be carried out in various ways, but a convenient one adopted by him was shown in *Fig. 1.* A large number of parallel flues F F F were placed on each side of the main flue M, to the stack. Those flues were situated at an angle to the main flue, and each had a small opening into it, so that it should only take its fair share of the draught; then the outer ends of each set of parallel flues were connected to a gathering-flue G, which, being connected with the main flue

Fig. 1.



beyond the system, and a door D being shut in the main flue, obliged all the fume to be distributed equally through the parallel flues, and such products of combustion as were not deposited found their way by the gathering-flues G G to the main flue and the stack. This plan he had put before his friend, Mr. Sopwith, some years ago, and it had been at work most successfully in Spain since 1882. There had been an inspection of the works by an independent officer on the part of the Patent Office to report whether the plan was at work. From that gentleman's report it appeared that 190,000 lbs. of fume were deposited in 6 months, and that the arrangement was most effective. He had a further report of an extension of the plan to more furnaces, and in 8 weeks there was deposited on an average 3 feet depth of fume in the flues; and as the flues covered a good deal of ground, an

Mr. Cowper. enormous amount was thus obtained. The fume contained about 67 per cent. of lead. An incline had been arranged to convey this large quantity of fume more conveniently back to the furnaces for treatment. In the case of the gold and silver works, the fume would not only contain lead, but gold and silver.

Mr. Adams. Mr. THOMAS ADAMS enquired when the Papers were written. The information might be of interest as enabling the members to judge to what extent the Papers were up to date.

Mr. Hayter. Mr. HARRISON HAYTER, President, said that the Authors were abroad, but perhaps Mr. Collins, sen., could state when his son's Paper was written.

Mr. Collins. Mr. J. H. COLLINS replied that the Paper had only just been finished.

Prof. Roberts-Austen. Professor W. C. ROBERTS-AUSTEN considered it would be difficult for any Institution, even one entirely devoted to the interests of mining and metallurgy, to have two Papers better than those read, illustrating the recent practice on the American continent of smelting argentiferous lead. He was glad to say that both the Authors had been his students, but his interest in them was not merely professorial, though he might say that he was glad to find that young men from the School of Mines could go to the United States, where so much care was devoted to giving miners and metallurgists a thorough education, and could make good careers for themselves, and send home useful and trustworthy Papers. He could have wished that there had been some references to recent work and to Papers which had appeared in Austrian and German journals, and in the American *Engineering and Mining Journal*, reference, for instance, to the excellent book published last year by Mr. H. O. Hofman.[1] But it should be remembered that the Papers had been written, so to speak, on the field of battle, where there was no possibility of reference to modern works; and, knowing the literature of the subject, he could assure the members that the Papers were, in all respects, well up to date. He might observe that if the pan amalgamator was the typical appliance for operations in which the treatment of gold ores was conducted by amalgamation with mercury, the forms of water-jacketed furnace described by the Authors were the typical appliance in the modern lead smelting in the Western States. He had studied the works in the smelting district of Freiberg, and had seen the Grant Works at Denver, where many of the

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[1] "The Metallurgy of Lead and the Desilverization of Base Bullion," New York, 1892.

operations described in the Papers were conducted very much as therein described; and there was certainly a great difference between the Continental and the American modes of procedure. It should be remembered that in these vat-shaped furnaces the ore and fuel were charged in pell-mell, but that very varied products found their way into the well, or crucible portion of the furnace at its base. The lead came down as metallic lead, and carried with it the precious metals and the bismuth; while copper came down mainly as sulphide, and the nickel and cobalt in combination with arsenic; iron found its way to the base of the furnace chiefly as slag. Those different materials arranged themselves by gravity, and could be separated. In the Freiberg district great care was taken to isolate the metals from the various products other than slag, and to bring all to account, even the small quantities of platinum which accompanied the precious metals. But in America, it was stated that the zinc was wasted, and that even speiss containing 12 ounces of silver to the ton was thrown away. He would be glad if the Authors would give some information as to those troublesome yet valuable associates of the precious metals, the tellurides, especially in relation to the loss of the precious metals which their treatment entailed. He wished to ask one or two questions about the slag. He was familiar with the slags which were treated at the Grant Works and with certain of the Mexican slags, and it appeared to him that those described by the Author of the first Paper were rather poorer in lime than was usual; but he supposed that the Author would agree to the American rule that slags should not contain more than 16 per cent. of lime, if as much as 10 per cent. of zinc was present in the furnace charge. The Author had stated that 8 per cent. of the slags were oxides of lead and of zinc. He should be glad to know what proportion he considered should be allotted to the zinc alone. There were two points that struck him, and would no doubt strike the metallurgical students present in the room, as of great interest. It had been stated that the whole of the precious metals could be collected in the lead, but in order to effect that collection, it was not necessary for the lead to exceed 10 or even 8 per cent. of the total furnace charge, and base bullion was then obtained which contained 400 ounces of silver to the ton. That seemed an extremely satisfactory performance. Copper had been employed with great success as an agent for collecting the precious metals, and when copper was so employed it was possible to use as little of it as 5 per cent. of the charge. That was interesting information, and he should like to hear

Prof. Roberts-Austen.

Prof. Roberts-Austen.

further details. No doubt 400 ounces of silver to the ton of lead would amount to some 80 ounces of lead for every ounce of silver collected; and that might seem large as compared with the 2 or 3 ounces of mercury to which was allotted the task of getting a single ounce of gold in ordinary amalgamation processes. But the conditions of working should be observed. There was a more or less pasty semi-fused mass; yet the lead had to go through that mass—had to find its way through the charge, take up the precious metal and carry it safely to the bottom. A new flux had been introduced—old tin cans, which were employed in considerable quantity in the furnace, not only with a view of affording sources of iron, but for the sake of keeping the charge open. The contents of those cans were well known to be extremely indigestible, and it was fortunate that a use had at last been found for them when empty. The value of the precious metal dealt with in the Papers was remarkable. The silver and gold, taken together, amounted to no less than £6,000,000. The gold value of the precious metals was about one-fifth of the total annual production of gold in the world, and about one-half of the amount of gold which the engineer and the metallurgist combined had converted into sovereigns during the past year at the English Mint; so that the amount of precious metal dealt with in the Paper, and representing the out-turn of about 9 works, was remarkable. One point that had struck him in reading the first Paper was the enormous advance that had been made in the engineering side of the question. Formerly metallurgy and chemistry were considered everything, and engineering was neglected. It was so when he assisted an old friend in smelting lead in Cornwall; but now all was changed. They had only to read the Paper and Mr. Hofman's book to see how efficiently the engineer had aided the metallurgist in recent metallurgical practice. With regard to the scale of charges and treatment, he wished to make one observation. In his evidence given before the Royal Commission on the production of gold and silver in 1887, he allotted 2*s.* as the cost of every ounce of silver obtained by the desilverization of lead. That figure was much disputed, especially by American authorities; but he was quite satisfied, after examining the scale of charges given in the Paper, that the 2*s.* would leave a very good profit for the extraction of an ounce of silver by the methods he had indicated. He wished to offer a word of gratitude to the President and Council of the Institution for admitting so many metallurgical Papers into its list. He thought he was right in saying that within the past two years there had

been no fewer than four metallurgical Papers read. Metallurgists were only too glad to have an opportunity of placing before engineers the difficulties they had, not only in extracting metals from their ores, but in adapting them for use. That usually involved either adding or abstracting a minute quantity of foreign matter, which would entirely change the mechanical properties of the metal, and render it serviceable. It was only by conferences like those that engineers could help metallurgists to overcome their difficulties, and that metallurgists could really appreciate the requirements of engineers. There were some other points he should have liked to raise as to details of the method of extracting the silver by zinc; but as the Authors were not present, he feared it would be of little use to ask those questions. Perhaps, however, Mr. J. H. Collins could state if it was found, in the desilverization, that the first zinc which came to the surface of the lead bath was specially rich in silver. Prof. Roberts Austen.

In reference to the concluding part of Mr. Rickard's observations, he remarked that American metallurgists had, in certain cases, adopted the reverberatory furnace when the precious metals had to be concentrated in copper, as was the case at the works directed by Mr. Pearce, at Denver. In American lead districts, the reverberatory furnace had not held its own, mainly because the ores were not, generally, sufficiently pure for treatment in the reverberatory; and where, as in the Mississippi Valley, the ores were suitable, the difficulty of obtaining skilled labour appeared to have been the main reason for not adopting the reverberatory in preference to the blast furnace. This reason may not have been justified, but the fact remained that blast furnaces were preferred. Doubtless, the adoption of a mixed system of reverberatory and blast-furnace treatment would be advantageous in certain cases.

Mr. W. W. Williams said he had just returned from Mexico, where he had had charge of the works described in the second Paper, which had been rather severely criticised in the first Paper. He would be able to prove that those works were carried on more economically than the El Paso works, which had been taken as a basis of comparison. He would first submit that it was hardly fair to make a comparison between works situated at El Paso (which, although it had a Spanish name, was in the United States), at the junction of four main lines of railway, where there were always plenty of men, with works at Las Trojes, in the centre of Mexico, a hundred miles away from any large town, where local labourers had to be put up with, and trained to Mr. Williams.

Mr. Williams. the work. Before making a comparison he wished to make three statements. Firstly, there was no ore so varying in its constituents as silver-lead ore. Iron and copper ores, especially when taken from the same districts, possessed great similarity; but in silver-lead ores, sulphides were as different from carbonates as the proverbial chalk from cheese. In the first Paper it was mentioned that at El Paso a carbonate ore was used containing 25 per cent. of lead, and large quantities of iron, to the extent of 50 per cent. Works using that could hardly be compared with works treating dry silicate ores, with a great deal of zinc and very little lead. Secondly, the Trojes ore differed very considerably from month to month. He had had men at one time working at one particular point in a mine, and bringing up ore which contained very little zinc and a great deal of iron; and from the same point, a month afterwards, it came out nearly all silica and zinc, and yet with the same quantity of silver in it. Thirdly, he would point out that the works had been, and still were, in a state of transition. A question had been asked as to when the Papers were written. The second Paper was written about 15 months ago, when the furnaces had just been put in place, but had not been worked very long. Two or three months after it was written, the Author of the first Paper wrote for information, and it was given to him, but he was warned that the works were entirely in a state of transition, and he must take the facts that were given with all reserve, because the proportions of mixture, &c., were being changed almost from month to month. That information was given about a year ago. In works extracting precious metals there were two divisions, showing themselves at once. The first was, whether they were using lead or copper as a base. There were few mines where they could use both, and choose which they would have. Then there was another division, not so apparent, but still more important, when making a comparison, viz., whether they smelted from their own mines, or whether they bought the ore and smelted it, practising what was called in the United States "customs" smelting. A "customs" smelter could please himself whether he would buy an ore or not; if he did not like it he need not have it. In smelting in conjunction with one's own mines, there was only a choice of two things,—either to smelt the ore, or to throw it away. If it contained too much silver to be dealt with in that way, it had to be either smelted or otherwise treated. He would ask how it was proposed to deal with an ore too rich in silver to throw away, containing perhaps 10 or 11 per cent. of zinc, and not more than 3 per cent. of lead. Perhaps the answer might

be that it should be crushed and concentrated, and the zinc then treated separately. Possibly that might do, but then other works would have to be erected. The zinc ore could not be thrown away, because the zinc carried silver quite as much as the lead. It was necessary to start expensive new works for treating one part of the material, or to smelt it. It had been stated in the first Paper that the total cost of smelting a ton of ore at El Paso was £1 9*s.* 9*d.*, and that at Las Trojes it was £1 10*s.* 8*d.*, a few pence more. At the same time it was mentioned that the price of coke at El Paso was £1 15*s.* a ton, and at Las Trojes £3 4*s.* 4*d.* He thought he had proved that, allowing for the price of coke, the work was being done cheaper at Las Trojes. Taking the figures given, and reducing them to the same denomination, it would be seen that at El Paso 646 lbs. of charge were smelted for 100 lbs. of fuel, and at Las Trojes 800 lbs. of charge for 100 lbs. of fuel. At the present moment Las Trojes was doing 1,000 lbs. of charge for 100 lbs. of fuel, which was a step in advance of any others that he had heard of. He was sorry that the Author had not accepted the invitation given to him to visit Las Trojes before writing the Paper, because he would have seen that they were not smelting their slag over and over again; but that they were using old slag, some inside the yard, and some from places 3 or 4 miles away, which only cost the carriage. It was slag, 50 or 60 years old, from ore which had been treated by the old Castillian furnaces; and all the silver had not been got out of it. He had seen such slag with 8 ounces of silver to the ton. Slag of that sort was very friable, and went easily through the furnace. He might mention a fact that seemed almost too strange to be believed, but was absolutely true. The charge had been arranged, and it had been settled that there should be so much litharge, so much lime, so much calcined and uncalcined ore; the matte from previous smeltings had to be put through, and a certain proportion of the slag also. If the slag was reduced no more charges were put through, and no less fuel was consumed. Five per cent. might be added to the slag, without increasing the amount of fuel; so that there was an advantage in putting an extra amount of the old slag through the furnace. At present slag containing 1¼ oz. of silver to the ton was turned out; not, as had been claimed for other works, ¼ oz. per ton; but if slag with 3 or 4 ozs. per ton were put in, and slag was produced with only 1¼ oz., it paid to smelt the slag. There were many ores containing 15 ozs. silver to the ton, which were less valuable than slag containing 5 ozs. to the ton, the latter being so much more easily smelted. With regard to

Mr. Williams.

Mr. Williams. matte, it was stated at page 147 that too much matte was made at Las Trojes. On page 160 it was stated that more matte should be made, but not put through the furnace. In his opinion matte was what a previous speaker had described water-jacket furnaces to be —a necessary evil, at any rate for the class of ore at Las Trojes. Matte was a product due to imperfect calcination. Shortly after he went to Las Trojes, he obtained permission to construct some roasting-stalls, by means of which the ore was calcined not only more quickly, but better; and the consequence was that the quantity of matte had decreased. It was mentioned in both Papers that the water-power there cost nothing; it was available at Las Trojes for ten and a-half months in the year, but still engines were needed for about 6 weeks at the end of the dry season. Another point raised was as to fuel. The charcoal at Las Trojes was cheap, but bad. The men had been accustomed to use charcoal, and, in fact, had no other fuel until about 3 years ago, when the railway was made. At the time when the second Paper was written, 7 parts of charcoal were used to 3 of coke. Two or three months afterwards, as would be seen by the first Paper, equal parts were used. Last autumn it was found that it was advantageous to further increase the coke and diminish the charcoal, and 3 parts of coke were used to 1 of charcoal, nearly reversing the proportions. That proportion could not be maintained, for, in such a locality, it was difficult to get regular supplies of fuel, and it had sometimes had to be varied according to what could be obtained. The San Luis Potosi Smelting Works used very hard coke, and no charcoal, but it was found at Trojes that with charcoal soft coke was better. Colorado coke was principally used. Mexican coke had been tried, but it did not give such good results. In the first Paper, it was said that the well became charged with lead in a few days. That might be the case at El Paso, but at Las Trojes the lead well was charged at the start, and it only held about twelve hours' supply. It was found that if the lead well was not charged, slag would issue through the siphon. He had the pleasure of seeing the works managed by Mr. H. F. Collins, and it was interesting to notice the ore converted direct into pig-copper. That certainly proved that he had got, what he described in the Paper as "a very docile ore, containing very considerable quantities of ferrous oxide and lime." A remark had been made about the use of old tin cans. He thought it was a very ingenious plan, but they were not used in the furnace. Old iron was largely used at Rio Tinto to precipitate copper in solutions in water. It had occurred to the Author that the

same plan would probably apply to copper when in a molten state, and he had introduced those tin cans with satisfactory results into a settler used before the slag was carried off. Even admitting the possibility of a comparison between the works described by the Authors of the two Papers, it should be remembered that in one case they were close to the United States, and in the other there was an additional 1,000 miles of haulage for the fuel, which would account for any difference if the works at Torreon were more economical. At the Grant and Omaha Smelting Works at Denver, there were 10 furnaces 33 inches by 100 inches in blast, and 8 more were under construction. There the matte was re-smelted; recently about 5 per cent. was being put back, and what they did nobody need be ashamed of doing. About 18 per cent. of lime was also used in the charge. Another large works was that of San Luis Potosi, where there were 10 furnaces 42 inches by 120 inches. All the smoke from these furnaces was conveyed under the yard and up a wooden stack 175 feet high. There was no smoke in the charging-floor, and simply a funnel or slit in the floor through which the charge was shovelled. He stood over it and there were no fumes at all. The length across the yard was not $\frac{3}{4}$ mile—perhaps not more than $\frac{1}{4}$ mile. The name of Mr. Pearce of Argo had been mentioned. Mr. Williams had had the pleasure of visiting the works conducted by that gentleman. They were very different from those which had been described and discussed. There were no blast-furnaces; and an interesting new furnace invented by Mr. Pearce was employed instead of the Brown O'Hara. It was called the "Turret" furnace. It had two arms, with cold air blown through them. Mr. Pearce considered that it was more economical, and that it required fewer repairs than the O'Hara furnace, which was driven by chains. It was stated in a pamphlet given to him by Mr. Pearce, that they were paying on about 80 per cent. of the gold ores. It had been stated by Mr. Bayliss, however, that at Montana they had paid all the gold and 95 per cent. of the silver, and he inferred that they saved 95 per cent. of the silver. He wished to learn the treating charges. It was better to pay on 95 per cent. of silver and charge $14 for smelting, than to pay on 100 per cent. and charge $16 for smelting—that was, it was better for the person who sold it. It was very easy for anybody to say: "You are working on a wrong process, and you should start something else." Companies had a considerable difficulty in deciding upon the right process to work, and it was very inconvenient and expensive to change a process. He had recently been in Virginia

Mr. Williams.

Mr. Williams. City talking to the foreman of the largest amalgamating works there, who had said: "We are all wrong here, we ought to smelt like you." Mr. Williams replied: "Wait till you have tried it; if there is anybody who ought to amalgamate and not to smelt, it is you."

Mr. Kitto. Mr. Benedict Kitto said he should be glad if some gentleman who had had practical experience in the modified form of the old English and Welsh furnaces as used in some of the larger smelting works in Colorado, would compare the results obtained therefrom with the results given in so much detail in the Paper. The water-jacketed furnace had been described by Professor Roberts-Austen as the typical furnace for silver ore smelting; but one would like to hear what could be said for the modification of the old English or Welsh smelting-furnace. The process of smelting which permitted speiss, containing 10 ounces and more of silver to be thrown away with the slag, could not be regarded as satisfactory. He agreed with Mr. Williams that it seemed hardly fair to compare the results obtained at El Paso, which was a customs smelting works supplied with different classes of ores, especially with those lead carbonates which were so useful in smelting, with works like that at Las Trojes, where only one class of ore had to be dealt with, and that refractory and difficult to treat. Some time ago he had submitted some of those Las Trojes ores to an inventor who had a new process for extracting silver from ores, and who, after assaying the ore, announced that he should concentrate the ore considerably. Mr. Kitto had replied that if he attempted to do so, he would lose a large portion of the silver. He had come to the conclusion, from examining the ore on a small scale, that it was impossible to concentrate the ore without a very heavy loss in silver; but the inventor in question had an original process of concentration, and was determined to try it. Mr. Kitto found in his tailings more than half as much silver as in his concentrates. The ore at Las Trojes contained a large amount of zinc, which was a troublesome thing to deal with in smelting silver ores. He had recently been experimenting upon a silver ore containing about 250 or 300 ounces of silver to the ton, and at the same time about 25 per cent. of zinc, with only 6 or 7 per cent. of lead. That ore was, he found, very difficult to treat so as to economically extract the silver. He thought they had got over one difficulty, that of roasting the ore without sustaining the heavy loss which usually occurred when ores containing such a high proportion of zinc were calcined. Still, the greater part of the zinc was left, and

the smelters did not like it. If a smelter, or any modification of existing smelters could be obtained, which could treat ores containing those large quantities of zinc, it would be most useful. Mr. Kitto.

Mr. Bennett H. Brough had listened with great interest and profit to the accounts given by the Authors of the marvellous development of the American metallurgical industry. At the same time he could not help being struck by the manner in which the labour-saving appliances in use throughout America were invariably accompanied by a disregard for the value of material. The same characteristic was noticeable in all branches of American metallurgical industry, and those who took part in the American excursion of the Iron and Steel Institute would remember that in the rolling mills in the Pittsburgh district, though most ingenious and elaborate devices for the automatic handling of ingots were seen, yet the amount of crop-ends that were produced was much larger than would be allowed in any works in Europe. Again, in the Connellsville coke region, there was not the slightest attempt made at collecting the by-products from coking. Similar examples could be cited from many other branches of industry. That state of things could not go on for ever; the time must come when more regard must be paid to the value of the raw material, and one could not help thinking that Americans would in time have to imitate the methods used in Europe in lead smelting, paying some attention to the recovery of the zinc, sulphur, bismuth and arsenic, which the Authors said were now entirely lost. In one of the Papers appeared some slight indication of the possibility of that tendency towards economy, in the statement that, at some of the works, the slag was used by the railway companies for ballast; but it seemed that the method employed was the clumsy one of running the slag from the furnace into trucks on tramways—a method which could not compare in any way with that adopted in the iron works of the Siegen district, where the slag, after granulation in water, was conveyed away by a wire ropeway and utilized for the manufacture of cement. A somewhat similar method had been seen by him at the Sudbury Nickel Works, but even there the slag was of no commercial value. On the other hand, on the continent of Europe, at the great copper works of the Mansfeld Company in Prussian Saxony, the slag industry had become of vast importance. There, slag from the copper works, after being de-vitrified by slow cooling, was used in the construction of paving-blocks, and last year more than 6,000,000 such blocks were made, showing to what an extent the utilization of Mr. Brough.

Mr. Brough. by-products might be carried. The Author of the first Paper had alluded to the narrow fissure veins of the Hartz mining district. Seeing that those veins attained the enormous thickness of 120 feet, that description could hardly be regarded as strictly accurate. In discussing the question of the dangers of lead colic, Mr. Rickard had mentioned a specific used in this country, where the lead smelters were dosed with sulphuric acid. On visiting the Mechernich lead works in Germany in 1891, Mr. Brough had found in use there a method equally efficacious and much pleasanter to the men. It consisted in compelling smelters before beginning work every morning to eat a piece of fat bacon; and that plan was found to answer remarkably well.

Mr. Terrell. Mr. WILLIAM TERRELL observed, with reference to the difficulties of blast-furnace treatment of ores that were rich in zinc and comparatively poor in lead, that in this country there was a method which would deal with those ores, if a reverberatory furnace were resorted to, viz., to mix such ores with oxide of iron if it could be obtained; and if not, to use old tin cans, first melting them in the reverberatory furnace to get rid of the zinc, after which they could easily be melted down in a blast-furnace, yielding bullion and good slag.

Dr. Ball. Dr. E. J. BALL was reminded by Mr. Terrell's remarks that the Freiberg slags contained up to 20 per cent. of oxide of zinc. The slags were very fluid, owing to the fact that the ores contained a considerable quantity of oxide of iron. Last year he had passed through Colorado to Idaho, and had visited a number of the smelting establishments *en route*. In regard to any criticism on the first Paper, it was difficult for those who had not visited the districts in question to fully understand the difficulties with which smelting was accompanied. As an illustration of the cost of living, and consequently of labour, in the case of one small smelter which he saw at Idaho, the smallest coin in use in the adjacent town, was a quarter of a dollar, and at Pueblo he was informed that half-a-dollar was the unit of value in everyday life. It was evident, therefore, that smelters could not treat at a profit such small quantities of speiss, containing a few ounces of silver, as those to which the Author had referred. Everything was done with a view of making profit with as small a quantity of labour as possible, and that particularly applied to smelting. Another point which, he thought, was rather passing out of view, was the consideration of the reasons for the failure of many of the smelters erected in the West. In the summer of 1890 or 1891 he visited British Columbia, and went to nearly all the smelting-

works erected there. A gentleman who had returned from that district only a few days ago had informed him that in the interval not one of those furnaces had been blown in. The reason for erecting them on modern lines was for the purpose of "booming" the adjacent real estate or mines, without any idea as to the cost of the material produced. A modern appliance had been mentioned which had been adopted for preventing the escape of fumes from the furnace. The appliance alluded to was in use at Freiberg a dozen years ago; it was not new. Many modern inventions or labour-saving appliances in the West were really older than had been supposed; still, he did not think it was fair to say that the smelting processes in England were better than those in the West, because the conditions were more favourable, and what would be best in the one case would not necessarily be so in the other. Dr. Ball.

Mr. T. K. Rose observed that Professor Roberts-Austen had remarked that tin cans were used for the double purpose of keeping the charge open and reducing the precious metals in the slag. A subsequent speaker had said their use was in reducing copper from the slag. Referring to the Paper, it would be seen that whatever the Author originally intended the tin cans for, he only admitted that he wished to keep the charge open and to reduce the precious metals. The slag preferred by the Author contained 46 per cent. of ferrous oxide; in which case much of the oxides originally present in the ore must have been reduced by carbonic oxide in the upper part of the furnace to metallic iron, consequently there must be a large percentage of metallic iron present when the tin can was added; therefore the use of the tin cans, if any, must necessarily have been to keep the charge open. He had been struck by the accuracy and fidelity of the descriptions of such of the smelting processes and furnaces of Western America as had been seen by the Author, particularly the descriptions of the lead-smelting process as carried on at Denver, Pueblo, and Leadville. There were one or two points, however, on which further explanation would have been satisfactory. He had observed in the Paper that one of the difficulties in smelting was the fineness of a large proportion of the ores offered. It might have been explained that this was due to two causes. One was that, in Denver at any rate, most of the ores in course of transfer from the miner to the smelter passed through the hands of public sampling-works, where the value of the ore was carefully ascertained. In order to do this, the whole was usually crushed by rolls so as to pass through a sieve of 2, 3, or 4 holes Mr. Rose.

Mr. Rose. to the square inch, thus making a good deal of fine ore. The other cause of the fineness of the ores was the large amount of sulphur in them, necessitating a preliminary roasting. To make this more effectual, the smelters crushed all sulphide ores not already finely divided. Thus at the Omaha and Grant Works at Denver, 150 to 200 tons of ore were reduced to the size of peas and even smaller by rock-breakers and rolls, as a preliminary to feeding it into the roasting-furnaces. He might add a few more figures which were supplied to him when on a visit to the Omaha and Grant Works in June, 1888. There were 440 tons of ore being smelted per day in the blast furnaces, one being set aside for fusion of matte. The consumption of fuel was 80 tons of coke and 15 tons of charcoal, besides 80 tons of coal in the roasting-furnaces, where 160 tons of ore and 60 tons of matte were roasted daily. The air to the blast-furnaces was supplied by blowers worked by a 250-HP. engine. At the time of his visit the yards contained ore of the value of $1,700,000. The charges for the blast furnace were made up on large mixing-floors. At the Grant Works, piles of ore were made from 6 to 10 feet deep and 100 feet or more in diameter, containing over 2,000 tons, composed of very thin evenly-distributed horizontal layers of different kinds of ore. When these piles were complete, vertical cuts were taken from them; and so the charges remained uniform for some time. Bullion was sampled by hollow punching, 2 cores being taken from each ingot. The cores from a carload of ingots were melted, and about four samples were taken. There was a slight ambiguity in one part of the Paper, where it was stated "gold is paid for at 95 per cent. of its full market value—about $18 per ounce." The mint value of gold in the United States was $20·67 per ounce fine; but smelters, he believed, always paid at the rate of $20 per ounce. In localities where miners would accept $18 per ounce as 95 per cent. of the value, smelters ought to prosper. The use of step-grates for roasting-furnaces at the Argo works, Denver, had resulted in great economy, as slack coal could be burnt satisfactorily. 1 ton of slack, he had been informed, was almost equal to 1 ton of large coal, and cost only $1·25 per ton, as against $4 for good flaming coal in large sized pieces.

Mr. Louis. Mr. D. A. Louis observed that among novel accessories in smelting-works, not mentioned in the Papers, was a centrifugal machine introduced at the Omaha and Grant works, at Omaha, for separating the globules of matte from molten slag; it was stated by its admirers to answer so well that, at the time of his visit in 1890

a similar plant had been shipped to Helena to treat the slags there. He thought it would be of interest if any information could be given as to the fate of that appliance. Its application, if successful, would result in the saving of much valuable metal, as well as the labour of picking over the slag by hand, referred to in the first Paper. The economy of treating slag or speiss containing a small quantity of silver, depended entirely on local conditions. He cited as an example of such apparently paradoxical economy, the fact that, in a small smelting-works in Montana, it was found expedient to smelt ore, even at the cost of some lead and other valuable constituents, because wood was scarce and coal dear. Fuel had to be economised, and the scheme was to let the sulphur replace it to a large extent. To this end, the silver and gold were concentrated in a copper matte in a hot-blast furnace; the blast being heated in a stove consisting of a vast rectangular chamber, through which the heated gases from the fire, at one end, circulated in one direction, whilst the blast traversed it, in 6-inch iron piping, in the opposite direction. The heavy arsenical fumes rolling out at the throat of the furnace, however, indicated the loss that was going on; nevertheless, the process was considered economical, and a larger smelting-works was being erected on the same principle in another district. In reference to the utilization of slag for cement, which had been mentioned in the discussion, it had not been so neglected as was supposed. The matter had been considered in the neighbourhood of a smelting-works where the slag was granulated, and where a suitable calcareous soil existed in the vicinity. A small grinding-mill was started, and a kiln, and large quantities of cement were made—for which, however, there was little or no demand. As to flue-dust, a striking contrast to the hot-blast copper-matting process alluded to, was furnished by the process in vogue at the Anaconda Works. The ore-bin at the Anaconda mills was constructed to contain 30,000 tons of ore. There calcination was conducted in Bruckner cylinders, and matting in reverberatories. There were ninty-six of these cylinders, each of 13 or 14 tons capacity, and the fumes, smoke, &c., ultimately passed into a long capacious flue of large section, built of masonry arched over with brick, following the slope of a hill terminating in the base of a high shaft on the summit. Considering the enormous amount of material used at the time of his visit, the amount of fume escaping was remarkably small; the weather, however, was then extremely cold. Mr. Louis.

Mr. J. H. Collins said no one was more sorry than he at the Mr. Collins.

Mr. Collins. absence of his son; but as he knew most of the works referred to, and was well acquainted with the processes carried on at Torreon, he would endeavour to reply to some of the points that had been raised. Particulars had been asked for, which were given in the Paper; and questions had been discussed as if they had not been referred to. For instance, Mr. Rickard said he found no mention of the important question of fumes and flue dust in the Paper. It might be that it did not treat the subject adequately; still, a considerable portion of the Paper dealt with that question. Again, it had been asked how the losses of the precious metals had been calculated. The particulars were given in the Paper. Many such questions would be found fully dealt with there. Then, again, many critical observations had been answered by subsequent speakers. Mr. Bayliss thought the Author had not done justice to the skill of the American smelters, when he said that they ordinarily utilized about 92 per cent. of the precious metal; he said it must be more than that, because they paid for more than that. A subsequent speaker objected on the very opposite ground, and said, so far as his experience went, not anything like 92 per cent. was recovered. Those remarks answered each other; and it might be that after all, the Author was not so very far wrong in his generalization. Some of the remarks made hardly seemed to be meant seriously, unless he had quite misunderstood them. Mr. Rickard had mentioned some smelting establishment where the output of silver was steadily and ordinarily 4 per cent. more than was shown by strictly accurate sampling and assaying. It reminded him of an examination question once put to him: "How would you detect hydrochloric acid in pure nitric acid?" All he could say with regard to an establishment where they got 4 per cent. more silver than accurate sampling and assaying showed there was in the ore, was, that he should not like to sell his ores at that place. Again, Mr. Rickard objected that there were too many details of construction in the Papers. He took it that any young man who went out to take charge of a smelting establishment or a mining establishment in an outlying district, away among the mountains, would not complain of Papers containing too many constructional details; and certainly those details would not be out of place in a Paper presented to the Institution of Civil Engineers. With reference to the question of clean slags, it was mainly, as had been said, one of local conditions. Where metal was cheaper than fuel and labour, there it was better to save fuel and labour; where fuel and labour were cheaper than the metal, there it was

better to save the costly metal. But it was not altogether a question of local conditions. Even in England attempts had been made to get copper slag too clean, even approaching the ¼ per cent. mentioned, and sacrificing three or four times the value of the copper saved in extra fuel. If that could be the case when coal could be got at 5*s.* or 6*s.* a ton, what would it be when coke had to be used at £3 a ton? With regard to the water-jacketed furnaces, it was the loss of heat which seemed to be the bugbear. The loss of heat in the water-jacket was not very much greater than in any other form of furnace. It was simply that the temperatures were much more localised. Any one going into a place where a large number of water-jacketed furnaces were at work would find that they did not radiate any large amount of heat; whereas on going into a place where there were furnaces of masonry, they would be found, after being at work for a short time, to radiate a large amount of heat. But this was not altogether a question of guess with the water-jacketed furnaces. With an ordinary masonry furnace, it would be difficult to ascertain what amount of heat was lost; but with the water-jacketed furnace, it was not at all difficult to come near the truth. In one of the furnaces described, the Author had stated that 7,600 lbs. of water were used per hour, and in the same furnace about 500 lbs. of coke were burnt per hour. The water, it might be taken, would be raised in that time about 55° Cent., *i.e.*, it would come out 55° Cent. hotter than it went into the jacket. He was speaking of a place where the water did not cool down very much before it was used over again. Working out these figures, it would be found that the total heat that went away in the water was between 9 and 10 per cent., and he much doubted whether, with an ordinary masonry furnace, the loss was less than that. One of the great advantages of these self-contained furnaces under the conditions in which they were used in America, was that they could be set up and used, though not of course to the best advantage, by men possessed of little metallurgical skill. They could even be used to smelt fine concentrates by using a low burden and a light blast. It was a mistake, of course, to suppose that the Author advocated the exclusive use of the water-jacketed furnaces; as he not only saw the necessity for reverberatory furnaces for some work, but would also acknowledge as soon as anybody that for some kinds of work they might advantageously use a blast-furnace constructed of masonry; still, for such conditions as he was dealing with up to the present time—transitory conditions, no doubt, to a great extent—the water-jacketed furnace

Mr. Collins.

Mr. Collins. had proved itself to be the right thing. With regard to the tellurides, referred to by Professor Roberts-Austen, he thought there would be no difficulty in getting the gold out of them. It would not much matter whether the water-jacketed or any other furnace were used—if the tellurides of gold were put into it, the gold would be obtained in the metal or the matte. As for most of the questions put, he feared he must leave them unanswered, they would perhaps be answered in a subsequent Paper. With regard to the zinc found in the slags, it could not be very high. Generally speaking, the zinc would be volatilised. At El Paso the zinc and sulphur and several other ingredients, were lumped together, and were all included in the 8 per cent. He thought Mr. Williams should be obliged to the Author for giving him the opportunity of making such an excellent explanation. He did not know that he could say any more than that with regard to his complaint of the comparison which had been made, except perhaps this: Mr. Williams had asked what the Author would recommend to be done with an ore containing 10 per cent. or more of zinc and only 3 per cent. of lead? The Paper had stated his recommendation. His idea would be to make two operations of it instead of one; to smelt it first, after roasting as well as possible, so as to have the richest matte that could be obtained, to roast the matte again, and then add the litharge. Some remarks had been made by Mr. Kitto which were based on a misconception. He would find that the slags referred to did not contain 10 ozs., but less than 2 ozs. of silver, that the 10 ozs. material was the speiss, which was not produced in any large quantities, and so need hardly be discussed there. Mr. Collins certainly would have been glad to hear something more of a method of roasting a zinciferous silver ore without driving off any considerable proportion of silver, for it was no doubt difficult to roast an ore containing a large amount of zinc, which was also argentiferous, without losing a good deal of silver. Mr. Brough had defined the condition of American work generally and had also pointed out that it was a transition condition. Later on, as labour became cheaper and the costs of transport were lessened, the relative importance of the material would come in, and American methods would approximate to the methods of English smelters. He was also inclined to think sometimes that English smelters would find it well to let their methods approximate those described in the Papers; for if they had sometimes wasted material for the sake of saving labour, he was sure that in this country they had sometimes wasted labour for the sake of saving material.

Mr. Collins

The Author's main position was very strong, although perhaps the title of the Paper was a little too wide. Instead of "Smelting Processes for the Extraction of Silver and Gold from their Ores," "Western," or "American Processes," or some such limitation, might have been used. But what he wished to bring forward was, that there were certain smelting processes for the extraction of gold and silver which were capable of large extension. The lead process, with its numerous advantages, was already pretty well known, and the Author hardly did more than describe and compare two typical works. The copper process was new, or nearly so. It was not generally applicable, but where it could be applied it was very valuable, since it admitted of so great a concentration as 30 or even 37 to 1 at one operation, and was moreover very cheap under favourable circumstances. The question of matte-smelting of concentrates and of pyritic ores was only lightly touched upon; but he agreed with the Author in thinking that, as roads and railways were extended, rendering the transport of fuel feasible, it would, following mechanical concentration in some instances, displace in many cases chlorination, the cyanide, Stetefeldt, and even the patio process, since it secured more of the valuable contents in a shorter time and at less cost. Further copper matte-smelting might even, in some cases, displace a lead-smelting process. An example of that came under his notice recently in connection with the Sunny Corner Works in New South Wales. There was a complex pyritic and zinciferous ore, which contained from 10 to 15 per cent. of lead and 1½ of copper. Neither the lead nor the copper were of any importance in themselves, but the ores contained always a good many ounces of silver and a certain small quantity of gold. For a long time, by a rather troublesome series of processes, involving more than one roasting, this mixed ore had been smelted on a lead basis. The lead produced was hard and impure, but of course it concentrated the silver and the gold. Within the last few years that process had been abandoned. The ore contained a good deal of zinc. It was found desirable to sacrifice both lead and zinc, to drive them away, to get rid of them as quickly as possible, and to work for a copper basis. Now the product was a copper matte of 30 to 40 per cent., in which the gold and silver were thoroughly concentrated. It was a much simpler process, and did not cost so much in labour. That was an example, and there would be others by-and-by, of lead-smelting being abandoned in the presence of a small quantity of copper for copper matte-smelting.

Mr. H. F. Collins, in reply, remarked that several of the points Mr. Collins.

Mr. Collins. raised during the discussion were answered in the Paper. The 92 per cent. of gold and silver referred to by Messrs. Bayliss and Louis represented, as stated on p. 124, only the amount directly recovered as bullion and matte in the first instance. Of the remainder, a variable portion was always saved in the flue-dust; but, even if none were recovered, it would be possible for a smelter to pay for 95 per cent. of the assay-value by suitably increasing the "treatment-charges;" and this actually happened in some cases, not only in America but also in Europe. With regard to the smelting of concentrates referred to by Mr. H. Louis, the usual method was to calcine them in long reverberatory furnaces, and to fuse them down with siliceous ores in the fusion-hearth, so as to render their manipulation easier. No reference was made to the Argo works near Denver, nor to the Anaconda works in Montana, because both those works were on a matte basis; and the present Paper was already too long to allow detailed treatment of the matte-process. With regard to the old tin cans, their use in lead-furnaces was to keep the charge open and to aid in reducing the precious metals; while in pig-copper furnaces, their most important function was to assist the reduction of the copper. His only claim to originality consisted in the application of tin cans and similar scrap to the settler through which copper-slags passed before reaching the slag-pots. They acted by chemically precipitating part of the oxidized and combined copper in the slag, as explained by Mr. Williams, and their use for this purpose had proved to be a valuable innovation. In reply to Messrs. Rickard and Brough about waste of material, he endorsed the remarks of Mr. J. H. Collins on the subject. It was true that valuable by-products were often wasted in America, and that losses of material resulted from over-driving the plant; but in Europe expensive attempts were sometimes made to utilize by-products and to save material which it would be better financial policy to lose. Moreover, the output of European smelting-works was too often small in proportion to the amount of plant and the capital invested, through working at low pressure and handling the stuff too frequently. Some improvement had no doubt taken place in English works since his experience of 10 years ago; but he remembered that the arrangements in some of the principal works in Swansea, which he visited in 1883, left much to be desired as regards economizing labour and fuel; while the losses of copper and of lead were no lower than at the best conducted American works. In answer to Prof. Roberts-Austen, the Author had no experience with tellurides, but all the great Colorado smelters treated auriferous

ores and concentrates, whether containing tellurides or not, by calcination in the long reverberatory furnaces described, fusing down and running through blast-furnaces, and returned 90 to 95 per cent. of the assay-value of such concentrates. With regard to the same speaker's remarks about lime in slags, the Author would venture to state as his opinion that too much attention had been hitherto directed to the relative proportions of iron and lime in slags. The feeling seemed to be gaining ground among practical smelters, that, provided the ratio of silica to bases remained constant, the relative proportions of iron and lime might vary within tolerably wide limits without affecting the percentage of extraction. Thus the following slags, though very different in their proportions of iron and lime, would give substantially the same percentage of extraction in the furnace; and, though the latter would perhaps need a little more fuel and a somewhat slower rate of smelting, that often became more economical and convenient when iron flux ores were scarce:— Mr. Collins.

—	Slag, No. 1. $3(2FeO,SiO_2)$ $+2CaO,SiO_2$.	Slag, No. 2. $4(2FeO,SiO_2)$ $+3(2CaO,SiO_2.)$
	Per Cent.	Per Cent.
Silica	32	32
Ferrous oxide	45	36
Lime	15	24
Oxides of lead and zinc, aluminium	8	8
	100	100

Attention had been drawn to the ores of Las Trojes and to his criticisms on the smelting-process adopted for their treatment. Mr. Williams had stated that works for the extraction of precious metals by smelting processes fell naturally into two classes, according to the agent or base employed for collection. That was not quite correct, inasmuch as three distinct agents or bases might be used, as mentioned in the Paper: (1) metallic lead, (2) metallic copper, and (3) iron—or copper-matte; of which the two latter were as distinct as the sulphide from the carbonate quoted by Mr. Williams. Only the first two were described in the Paper, owing to lack of space, but the last was becoming increasingly important. Stress had rightly been laid by Mr. Williams on the fundamental difference between the ores treated at El Paso and at Las Trojes respectively; but that speaker had failed to grasp the inference that a process which was eminently suitable for one

Mr. Collins. class of ores and one set of conditions, might be altogether unsuitable for another class of ores and a totally different set of conditions. His criticism of the large amount of slag smelted had been based upon a misconception; but, as regarded his other strictures, he adhered to the view expressed in the Paper. The challenge thrown out to him, to say what ought to be done with ore like that of Las Trojes, had been anticipated on pp. 147 and 160 of the Paper, but the following details would explain more clearly his recommendations:

(1) Nothing but ore, slag and fuel should be run through the ore-furnace, except limestone-flux when necessary.

(2) The bulk of the ore should be stall- or kiln-roasted, as thoroughly as possible; and just enough raw ore should be added to produce matte in the proportion of 10 per cent. of the weight of ore charged. This iron-lead matte would average 150 ozs. per ton, and the slags would, if passed through a settler, be poorer than they were at present.

(3) The matte should be thoroughly roasted, preferably in a Brückner or other revolving-cylinder furnace; after which, while still hot, it should be charged into a reverberatory lead-furnace, with about one-fifth part of its weight of litharge, and small quantities of rich siliceous ores if obtainable.

(4) The lead-bullion, containing upwards of 700 ozs. of silver per ton, should be cupelled direct, the slags from the reverberatory furnace going back to the ore-furnace.

The necessary modifications of the plant for the adoption of this process would take some time, though the cost would not be great; once in steady working order, however, the saving in silver would be from 2 to 4 per cent. on the total amount treated, and the saving of lead would be much greater; there would also be a considerable saving in labour, on account of the larger quantities of ore put through the ore-furnaces and on account of the smaller amount of bullion to be refined. He believed it was tolerably safe to predict that, within the next 10 or 15 years, the matte-process above sketched out (with such modifications as might be rendered necessary by local conditions) would replace the ordinary lead-smelting process—not only at Las Trojes, but at all places where similar ores were met with in large quantities and had to be treated on the spot.

Mr. Malcolmson. Mr. J. W. Malcolmson, in reply to Mr. T. A. Rickard's remarks, to the effect that undue stress had been laid upon the utility of water-jackets, pointed out that the water-jacket was not an evil; no material part of the furnace-heat was lost, because the jacket

was always covered with a skin of slag which was practically a non-conductor. If it were possible to dispense with a water-jacket, it would be bad policy to do so. He had worked brick-furnaces, and considered the disadvantages of walls 3 feet thick, and the consequent difficulties of handling the furnace-charge, compared with the convenience and ease experienced in reaching the charge through a 6-inch cooled partition, alone afforded sufficient justification for the employment of water-jackets. Since the Paper was written, he had enjoyed opportunities of visiting most of the large smelting-works in Mexico, and had considerably modified his views with regard to the economical value of round furnaces; indeed, in the north of Mexico, the rectangular furnace was the only form used, and the tendency was to considerably enlarge its dimensions at the smelting-zone. With regard to the statements made as to the lowness of the grade of the base bullion produced at Las Trojes, he entirely agreed with the Author of the first Paper; but, at the time alluded to, the condensing-chambers and flues were not in operation, and an undue loss was feared on this account in enriching to any greater extent. In his opinion, too, the more extended application of matte as a vehicle for concentrating the silver and gold at Las Trojes, might be considered, especially as no important changes would be required in the existing plant. In a few districts of the United States, ores approximating closely in character and composition to those of Las Trojes, were treated satisfactorily in that way, with a consumption of less than one-fourth part of the fuel used at the Las Trojes smelting-works. The literature on this subject, however, was scanty, and any contribution respecting the details of actual operations would be much appreciated by metallurgists, especially by those who were working among the dry sulphide ores of Mexico. Mr. Malcolmson.

Correspondence.

Mr. D. W. Brunton stated that the smelting-furnace generally preferred in Colorado, was the sectional cast-iron water-jacketed furnace, 120 inches in length and between 34 inches to 42 inches wide at the tuyeres. Furnaces of larger size had been built; but while it was found that they would smelt without difficulty, there was no increase of economy in working, because the former furnace Mr. Brunton.

Mr. Brunton. consumed as much material as one gang of men could handle. The fuel employed was principally El Moro[1] and Cardiff coke with charcoal, in the proportion of 5 or 6 parts of the former to 1 of the latter. At the Harrison works in Leadville, experiments were made substituting coal for a portion of the coke, with good results, but other experiments in this direction had proved unfavourable, the zone of fusion being apparently raised too far above the tuyeres. In nearly all Colorado coke the percentage of ash was exceedingly high—much more so than was usually stated in published tables on that subject; but it was a singular fact that the coke which carried the highest percentage of ash under equal conditions yielded the cleanest slags. The keen competition among smelters, brought about by the increase in the number of furnaces, and decrease in the production of ore due to the decline in the price of silver, had rendered necessary every possible improvement in the working of the furnaces and in the handling of material. Until recently, the slags from furnaces were wheeled in slag-pots to the edge of the tip; but within the past year the lead-smelters had taken the cue from the copper-smelters, and had begun to granulate the slags. The slags were granulated by being allowed to fall into a running stream of water, which carried the particles away to some convenient tipping-ground, where, instead of being allowed to accumulate, they were generally used for railway-ballast or road-metal. There were certainly other practicable methods for decreasing the loss in fume besides that of increasing the lengths of the flues, &c. The St. Louis Smelting and Refining Company, at St. Louis, Mo., had, for some time past, been using a water-spray fume-recovery process with excellent results. The operation was practised in a large tile-chamber, and the tiles were not affected to any great extent, whilst the recovery of the valuable portions of the fume was nearly complete. The Globe Smelting and Refining Company, of Denver, had a large plant for the recovery of fumes, which was successful in every particular, and saved, as far as tests had yet been able to indicate, all the silver and lead which escaped from the furnaces. The system consisted of passing the fumes through a number of long woollen bags, arranged as vertical pipes closed at the upper ends, through which the gases were forced and which intercepted every particle of fume; so that the gases, as they passed away from the bag-building, were perfectly clear and colourless. The fume was either shaken down from the

[1] Made from Colorado lignite.

bags, or fell of its own weight; it formed a soft brownish-black powder of the following composition: Mr. Brunton.

Ag.	Pb.	Zn.	As.	Fe.
Ozs.	Per cent.	Per cent.	Per cent.	Per cent.
4	75	3	1·3	0·5

All of the metals in it existed as sulphides. This material ignited readily and burned slowly into a crisp cinder, leaving it in the best possible condition for blast-furnace work. One of the most expensive operations connected with smelting was the roasting of the steadily-increasing quantity of "sulphide" ores. O'Hara mechanical roasting-furnaces had been introduced by several smelting establishments. This roaster consisted of a long double-hearth reverberatory furnace, in which the ores were stirred by narrow steel hoes placed upon a carriage which was drawn through the furnace by iron chains. The de-sulphurization of the ores and the freedom from lumps was all that could be desired; but the rapid wear of the chains and carriages, together with the noise produced by the heated dry axles as they were dragged along the hearths, formed a serious drawback to the working of the furnace. The Boston and Colorado Smelting and Refining Company of Denver had in operation one furnace, and were erecting two in addition, which were in effect circular reverberatory furnaces, in which the ores were stirred by small steel hoes secured to radial arms of 5-inch gas-pipe. The latter projected from a hollow revolving post, the whole being prevented from overheating by a current of cold air forced through the post and arms by a blower. At the works of the Arkansas Valley Smelting Company of Leadville, revolving cylinder ore-roasters were used with petroleum fuel. Those furnaces did good work, but required much care and attention, as overheating in the slightest degree caused the ore to become pasty and to form lumps. The immense waste-heaps of basic slags produced at Leadville from 1879 to 1885, when "iron" ores were in excess and competition was not strong, were being utilized by the Holden Smelting and Refining Company, who had two cast-iron sectional water-jacketed furnaces, each 36 inches by 130 inches, in operation, and two more of the same size in process of erection. The daily charge in each one of these furnaces was 90 tons of slag, 45 tons of ore, and about 7 tons of burnt lime, with 11 per cent. to 12½ per cent. of fuel, which was sometimes a mixture of coke and charcoal, but was generally pure coke. The pressure of the blast employed varied from 10 ozs. to 13 ozs., and the slags produced averaged 32 to 38 per cent. of silica, 11 to 18 per cent. of lime, and 23 to 28 of iron and

Mr. Brunton. manganese. The lead in the charges varied between 7 per cent. and 11 per cent., and that in the slags between $\frac{1}{5}$ per cent. and $\frac{3}{4}$ per cent. Throughout the West, ores were sometimes purchased by the smelting companies direct from the mines, but more frequently from the numerous sampling works scattered throughout the mining districts. While only gold, silver, lead, and sometimes copper, were paid for or mentioned in the bid of a smelting company for any particular lot of ore, every element in its chemical composition was taken into consideration in calculating its value; and the results obtained by this method of calculation were added to or subtracted from the fixed smelting-charge, which in Denver and Pueblo was usually assumed to be $6.00 per ton. Fortunately it was an easy matter for engineers to ascertain the value of ore in any of the Western States, as the smelting-charges, everywhere throughout the West, were the Denver or Pueblo rates plus the freight from the mines to those points. Though not always strictly adhered to, that was usually the rule for smelters situated anywhere between the Canadian boundary and the Mexican frontier. When in any district as Salt Lake at the present time, where the local demand for ores exceeded the supply, the local smelters decreased their smelting-charges sufficiently to prevent any ores from leaving the district; but this occurrence was so infrequent that the engineer, in calculating the value of ore, would make no mistake in following the rule indicated. Scarcely two of the large smelting companies employed the same method in calculating the value of ore, and, further, the rates, of course, changed slightly with the ratio of supply to demand; but, on an average, the following Table of values was nearly correct for all ores. The actual prices paid for silver and lead varied daily with quotations from the New York markets.[1]

Table of Values (Denver or Pueblo).

Ore.	Debit.	Credit.
	Dollars.	Dollars.
Au per oz.	..	19·00
Ag „ (95 per cent. N.Y. quotation)	..	..
Pb per unit, with N.Y. quotation 4 cents per lb.	..	0·50
Fe „	..	0·15
CaO „	..	0·10
Mn „	..	0·15
SiO_2 „	0·13	..
$BaSO_4$ „ small percentages occasionally disregarded	0·05	..
Zn „ „ „ „ „	0·30	..
S „ „ „ „ „	0·15	..

[1] A unit is 1 per cent. of the U.S. ton, *i.e.* 20 lbs.

Mr. Brunton.

As an example, an ore of the following composition :—

Au.	Ag.	Pb.	SiO_2.	CaO.	Fe.	S.	Zn.	$BaSO_4$.	Mn.
Oz.	Ozs.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
0·3	30	5	14	8	6	12	7	24	4

would be calculated by the Table above given in the following manner—showing that the ore would have a net value in Denver or Pueblo of $21·52 per ton :—

Ore.	Debit.	Credit.
	Dollars.	Dollars.
Silver, 84 cents per oz. Lead, $4·00 per 100 lbs.		
Au, 0·3 oz. at $19·00	..	5·70
Ag, 30 ozs. at 95 per cent. of 84 cents ($0·798)	..	23·94
Pb, 5 per cent. at 50 cents	..	2·50
SiO_2, 14 per cent. at 13 cents	1·82	..
CaO, 8 per cent. at 10 cents	..	0·80
Fe, 6 per cent. at 15 cents.	..	0·90
S, 12 per cent. at 15 cents	1·80	..
Zn, 7 per cent. at 30 cents	2·10	..
$BaSO_4$, 24 per cent. at 5 cents	1·20	..
Mn, 4 per cent. at 15 cents	..	0·60
Smelting charges per ton	6·00	..
Net value per ton in Denver or Pueblo	21·52	..
	34·44	34·44

At the present time there was scarcely a smelting-plant in the West that was not planning improvements, and there was every prospect that a greater advance would be made in the future than in the past.

Mr. Keller.

Mr. H. A. Keller, of Butte, Mont., observed that it often became necessary to produce, in the lead blast-furnace, slags of varying composition. It might be of interest to mention some commonly-used slag-types, serving as guides. They were expressed by the following simplified formulas :—

(1) The one-quarter slag—

$$3(FeO, SiO_2) + CaO, SiO_2 + 3(2FeO, SiO_2) + 2CaO, SiO_2.$$

(2) The one-half slag—

$$\left.\begin{matrix} 2FeO, SiO_2 \\ FeO, SiO_2 \end{matrix}\right\} + 2CaO, SiO_2.$$

(3) The three-quarter slag—

$$2FeO, SiO_2 + 2CaO, SiO_2.$$

(4) The 1 : 1 slag—

$$\left.\begin{matrix} 2FeO, SiO_2 \\ FeO, SiO_2 \end{matrix}\right\} 2(2CaO, SiO_2.)$$

(5) The 1 : 2 slag (rarely produced) $2FeO, SiO_2 + 5(CaO, SiO_2)$.

Mr. Keller These ratios were those of FeO to CaO, as would be seen from the following percentage compositions, in which RO represented impurities, mainly ZnO and Al_2O_3.

(*a*) Theoretical Percentages.

—	¼ Slag.	½ Slag.	¾ Slag.	1 : 1 Slag.	1 : 2 Slag.
SiO_2	33·33	30·47	28·73	31·77	40·29
FeO	45·00	38·27	34·46	28·60	16·12
CaO	11·67	21·26	26·81	29·63	33·59
RO	10·00	10·00	10·00	10·00	10·00
	100·00	100·00	100·00	100·00	100·00

(*b*) Percentages used in Practice.

—	¼ Slag.	½ Slag.	¾ Slag.	1 : 1 Slag.	1 : 2 Slag.
SiO_2	30	32	34	36	40
FeO	48	38	32	26	16
CaO	12	19	24	26	32
RO	10	11	10	12	12
	100	100	100	100	100

It might be stated that, other things being equal, the percentage of SiO_2 varied directly with that of CaO and indirectly with that of FeO. Although he had shown copper sulphides to be the most efficient, it was sometimes preferable to desilverize rich slags with lead ores in a furnace with a crucible. This method had the advantage of concentrating most values in bullion directly—a product that was in some places more marketable than mattes. Lead sulphides, being abundant, could usually be purchased at a fair figure. A limited percentage only was required to keep the crucible open, since such a slag-furnace could be made to run very fast. Such sulphides, however, generally contained large amounts of zinc, and did not admit of much of this impurity in the slags to be treated. To save coke, as well as to avoid preliminary roasting, a blast heated to 400° or 500° Centigrade, was sometimes employed in smelting sulphides in the blast-furnace. That variety of matte-smelting had of late been sometimes spoken of as pyritic-smelting. A large percentage of coarse sulphides (especially cupriferous), easily parting with

their sulphur, such as pyrites, was necessary to give good results with this process. It was frequently found advisable to feed flue-dust with the regular ore-charge into the fusing-hearth. Although in so doing the metallurgical losses were admittedly high, it had an advantage in avoiding extra labour, besides furnishing a product eminently fitted for blast-furnace use. Further, no large percentage of siliceous clay had to be re-smelted, which might have been used for agglomerating purposes. Mechanical roasting-furnaces of improved construction had only recently gained entrance into western lead-works, though they had been successfully employed for some time in the calcination of copper ores. Such furnaces, when properly designed, besides insuring constant and uniform stirring, involved important principles of economy, viz., large capacity, coupled with the saving of high-priced labour and fuel. Mr. Keller

Mr. Walter McDermott observed that it was absolutely certain the old brick furnaces had only been given up in the United States in favour of water-jackets for obvious commercial advantages, the chief of which consisted in freedom from the stoppages and consequent expense and delay caused by blowing out and blowing in of brick furnaces for repairs. This advantage alone, in connection with the consequently increased capacity, was far more than sufficient to outweigh the slightly increased consumption of fuel owing to the artificial cooling by the water-jackets; and again it had been found in actual smelting operations, that the artificial cooling was a direct advantage, by allowing the more rapid running of the furnace without producing excessive heat in its lower part. Capacity was the essential of commercial success from the American point of view with the conditions of working which obtained there. Some water-jacketed furnaces of American pattern had lately been erected at Swansea and were working satisfactorily. Mr. McDermott.

Mr. F. J. Warner observed that, a few years ago, a furnace of about 42 inches diameter or square section at the tuyeres was generally deemed the largest size of blast-furnace which could be employed with advantage in the reduction of lead-ores, any increased sectional area at the tuyeres leading to imperfect reduction of that portion of the ore which reached the fusion-zone beyond the influence of the blast. While no lateral extension of modern furnaces had been found practicable, the longitudinal enlargement to 10 feet or even 12 feet—forming oblong furnaces—had immensely increased their productive power without increasing proportionately the costs of smelting. Again, under Mr. Warner

Mr. Warner. similar conditions it was evident that water-jacketed furnaces were supplanting the old built furnaces. Water-jacketed furnaces wasted heat, but to no greater extent than brick furnaces having walls insufficiently thick to prevent the convection of heat by atmospheric air. In many of them the barbarous expedient, described as in use at Torreon, of spraying water on the external iron casing, had frequently to be adopted. The heat carried away and lost by the water-jacket was more than compensated for by the greatly prolonged campaign and diminished outlay in repairs, which resulted from the employment of water-jacketed furnaces. If any further argument were needed in favour of their use, it would be found in the nicety with which it was possible to calculate in advance the composition of the slags from the smelting operation. With furnaces lined with inferior clay, which fused away in a few hours, it was impossible to do this with precision, and the metallurgist in consequence lost control over the smelting-operations. When galena concentrates were calcined in reverberatory furnaces for the removal of sulphur, it was customary to expose the calcined ore at the close of the operation to the higher temperature prevailing close to the bridge of the furnace, so as to agglomerate the finely-divided particles into lumps suitable for smelting in the blast-furnace. The ore should be semi-fused, but actual melting or any process of slagging was carefully avoided. In conclusion, he would ask why this product had been described as "slagged sulphide ore," instead of "agglomerated ore," by which term it was usually known.

. Wingham. Mr. Arthur Wingham pointed out to the Author of the first Paper that, at the Spring meeting (1892) of the Iron and Steel Institute, there was described a new specially-constructed slide-rule for use in the calculation of furnace-charges and slags. The rule could be used in the present series of the Author's calculations with advantage, as there were scales on it which would meet every case of chemical equivalents that had been mentioned. It would convert the various values of the chemical substances one into another, and would measure off their basicity or acidity, as the case might be. By this means a considerable amount of time might be saved. These calculations were trifling in themselves, but were irksome and sometimes confusing. The slide-rule mentioned had been specially made to obviate this; and to enable any one to ascertain the equivalent values of quantities of bases and acids without resort to the combining weights.

7 February, 1893.

HARRISON HAYTER, President,
in the Chair.

It was announced that the several Associate Members, whose names were undernoted, had been transferred to the class of

Members.

THOMAS HUDSON BEARE, B.A., B.Sc., F.R.S.E.
EDWARD MANISTY.
DAVID CARNEGY SIMPSON.

Also that the following Candidates had been admitted as

Students.

FREDERICK RUSSELL CANNING.
FREDERICK SHEWARD CARTWRIGHT.
JAMES CONWAY, A.K.C.
FRED GLENDINNING.
FRANK LATHAM.
JOSEPH MELI.
THOMAS RICHARD NOLAN, B.A.
CHARLES JOHN RAFAREL.
JONAH WALKER SMITH.
JOHN FRANCIS CLEVERTON SNELL.
GEORGE FREDERICK SQUIRE.
WILLIAM STRATFORD STRETTLE.

The Candidates balloted for and duly elected were: as

Members.

FRANCIS MICHAEL COTTON.
RICHARD HENRY DORMAN.
ANDREW MORTON.

Associate Members.

HERBERT EDWARD ALLEN, Stud. Inst. C.E.
FREDERICK RHODES ARMITAGE, B.A., Stud. Inst. C.E.
HUGH GARRATT FOSTER BARHAM, Stud. Inst. C.E.
JOHN JOB CREW BRADFIELD, B.E.
ARTHUR WALTER BRADLEY, Stud. Inst. C.E.
JOHN GEORGE CAREW-GIBSON.
EDMUND CLARKE.
FRANCIS GEORGE COLES, Stud. Inst. C.E.
WALTER AUGUSTUS DUCAT.
WALTER EMMOTT.
THOMAS HANNING.
REGINALD HEPBURN HEATH.
WILLIAM HENN HINDE, Stud. Inst. C.E.
BERNARD HUNT, A.R.S.M., Stud. Inst. C.E.
EUGENE JOHN CHARLES KEELAN.
THOMAS KIDD.
GEORGE LIVINGSTONE.
JOHN MONASH, B.C.E.
JAMES MONTGOMERIE PEARSON.
ARTHUR BOYD PRICE, Stud. Inst. C.E.
WILLIAM ROBERTS.

Associate Members—continued.

George Anselm Henry Rowney, B.E.
Frederic David Sharp, Stud. Inst. C.E.
Ivon Algernon Sparks.
Jonas Molesworth Stawell.
John Thompson.
Ernest George Tidd.
Thomas Patrick Travers.
Frederick James Wellington Vereker.
Robert Willsher Weekes, Wh.Sc., Stud. Inst. C.E.
John White, Stud. Inst. C.E.
Joseph Henry Woolcock, Stud. Inst. C.E.

The discussion upon the Papers by Mr. H. F. Collins and Mr. J. W. Malcolmson on "Smelting Processes" occupied the evening.

14 February, 1893.

HARRISON HAYTER, President,
in the Chair.

(*Paper No. 2666.*)

"Electrical Railways: the City and South London Railway."

By EDWARD HOPKINSON, M.A., D.Sc., M. Inst. C.E.

FIVE years have elapsed since the Author had the honour of describing before the Institution the electrical system of traction adopted on the Bessbrook and Newry Tramway,[1] at that time the only line in the United Kingdom upon which the operation of trains as distinguished from individual tramcars had been carried out electrically. The line has been worked since October, 1885, with perfect regularity, and at a cost satisfactory to the proprietors. A Table showing the traffic upon it in successive years, and the cost of haulage, is given in the Appendix. In the course of the discussion upon the Paper alluded to, it was shown that the United States were conspicuously in advance of this country in the application of electrical traction to street tramways. At the present time, in almost every town in America, horse-traction has been either wholly or in part superseded by electrical traction; and it was stated, during the last Session of Parliament, in evidence before a Joint Select Committee of both Houses, appointed to consider the Electric Railway schemes proposed within the Metropolis, that in the year 1892, the number of electric tramways in the United States was 436, with 3,532 miles of track, and 5,851 motor cars, travelling in the aggregate 50,000,000 miles, and carrying 250,000,000 passengers annually. Although the advance on the Continent has not been so marked as in the United States, still many important city tramway systems are now worked electrically. On the other hand, during the past five years, the 8 British and Irish electrical tramways, aggregating 22 miles of track, have been reduced by three, on account of the abandonment of electrical working on those lines, whilst only 6 new lines have been added to the list, making 33¼ miles of track in all. Such a disparity as this is indeed difficult of explanation. In the use of accumulators for tractive purposes, the experience of all

[1] Minutes of Proceedings Inst. C.E., vol. xci. p. 193.

countries has been equally discouraging, and on few of the lines upon which the system had been tried has it come into permanent use. The advantages of such a system are universally recognized, but repeated and protracted experiments have proved that, with the types of accumulators at present generally available, the cost of maintenance is prohibitive; and that the several present well-known forms of accumulators, which are doing excellent service in connection with electric lighting, must be greatly improved before they can be generally adopted for tractive purposes. Many improvements have recently been introduced, tending to diminish the depreciation to which the plates of accumulators are subject when employed under the difficult conditions obtaining in tramway work, and there can be no doubt that success will be ultimately achieved. Again, in conduit systems, little more has been done abroad than in England. The line constructed at Blackpool, in 1886, still remains the only one of that type in England; on the Continent there are but a few examples of the system—the Buda Pesth tramways, which are on an extensive scale and are worked with great success, being the most notable of them; whilst in the United States, 9½ miles of tramway, out of the total of over 4,000 miles worked electrically, are on the conduit system. Probably the considerable first cost of construction is the chief cause of the slow progress made in this direction.

In the United States, electrical traction has become general entirely with overhead systems of conductors, whilst in England exist only the two working examples of the short line at Leeds, comprising 2 miles of double and 1½ mile of single line on the Thomson-Houston system, opened for traffic in October, 1891, and the recently-opened line of the South Staffordshire Tramways Company, 7½ miles in length. It is generally stated that the reason for overhead systems failing to find a footing in English towns, is the objection on the part of municipal authorities to the more or less unsightly erections involved thereby in the streets. This explanation has not been refuted, and no better one has been offered; and it is to some extent substantiated by the fact that, only comparatively recently, Boston, with one of the largest tramway systems in the world, adopted an overhead conductor, whilst Philadelphia and New York are still without this form of electrical traction on their extensive lines. The line at Leeds will be useful in testing the reality of this apparently unsatisfactory explanation. If, however, in street tramways, English practice has fallen short of American practice, in another direction it has advanced much further than anything that has been attempted

in other countries. At the conclusion of the discussion on his Paper on "the Bessbrook and Newry Tramway," the Author expressed an opinion that enough had been shown to prove that the system of electrical traction with a continuous conductor was applicable to the great schemes of overhead and underground railways in our large towns. An opportunity for a practical test soon afterwards presented itself.

In the session of 1884, the City of London and Southwark Subway Company obtained Parliamentary powers for the construction of a subway from King William Street in the City, to the Elephant and Castle in Southwark. Mr. J. H. Greathead was the engineer of the undertaking, and Sir John Fowler and Sir Benjamin Baker were the consulting engineers. In pursuance of the original intention, contracts had been arranged for working the lines on the cable system, but the success that had attended the Bessbrook and Newry line, and the progress made in electrical traction in the United States and on the Continent, induced Messrs. Mather and Platt, of Manchester, to make definite proposals to the directors of the Company, for working the line electrically, and to submit designs and estimates. After a most careful investigation of the whole subject, during which various schemes of electrical working were considered, their plan of electrical working was adopted, and a contract was made with them in January, 1889, for its execution. This contract provided for the supply of 14 locomotives to draw trains consisting of three carriages accommodating 100 passengers, and weighing $4\frac{1}{4}$ tons each, and the generating-plant was to be sufficient for working a service of 20 trains per hour. The contractors further undertook to work the line for a term of two years, or to guarantee the cost of haulage for a similar period, at the option of the Company. In October, 1889, a locomotive, the design of which is described below, was run experimentally on a short section of the line; and a few months later a second locomotive of a different type was experimented with—the original design being finally adopted. The works were formally opened by H.R.H. the Prince of Wales, accompanied by H.R.H. the late Duke of Clarence, on the 4th of November, 1890; and on the 18th of December, the line was opened for public traffic.

It is no part of the Author's intention to refer to the details of design of the City and South London line, except to such extent as may be necessary to explain the electrical working; much less to deal with the system of constructing the tunnels, which has made the formation of such a railway possible; but he proposes to describe as briefly as possible the electrical plant adopted, for the

design of which he was responsible, and the results obtained in working it.

The line consists of two independent tunnels, formed of cast-iron rings. The sleepers are transverse, resting directly upon these rings, and the rails are spiked thereto, and leave a minimum headway of 9 feet from the rail-level to the highest point of the tunnel. Fig. 1, Plate 5, shows a section of the tunnel and the space available. Where the line passes under the Thames between Great Dover Street and King William Street, there is on the up-line a down-gradient of 1 in 30 for a distance of 264 feet, and an up-gradient of 1 in 30 for 462 feet, and on the down line a down-gradient, with the traffic, of 1 in 14, followed by an up-gradient of 1 in 30. At other points of the line the gradients are not severe, the principal being an up-gradient of 1 in 100 approaching Stockwell Station. The total length of the line is 3 miles 270 yards. There are four intermediate stations.

Generator-Station, Fig. 2, Plate 5.

The generator-station is situated at Stockwell, at a distance of about 500 feet from that terminus. There were originally 6 boilers of Lancashire type, each 28 feet long and 7 feet in diameter, fitted with Vicar's automatic stokers. The boiler-floor is 12 feet 6 inches below the ground-level, and the boiler-house is roofed over except immediately above the stoke-hole, so as to provide room for a fuel store. By this arrangement the fuel can be shovelled direct into the hoppers of the stokers. Two similar boilers have subsequently been added. The steam-pressure at the boilers is 140 lbs. per square inch. In addition to providing steam for the electric generating-engines, the boilers are required for producing steam for the powerful hydraulic plant, and the auxiliary engines for the repairing-shop, the compressed-air pumps, and the hauling-engine for drawing the locomotives and carriages up the inclined way connecting the Stockwell terminus with the depôt. The boilers are set on Livet's principle, and are arranged in two groups of four, with independent flues and chimneys. No economizers are provided. The steam-pipes from the two groups are arranged so that either or both can be connected to the main pipes crossing beneath the yard to the engine-house, otherwise there is no duplication of the steam-pipe system. The exhaust steam from all the engines passes by a single pipe through the water-heaters to the chimney. As there is no water available for condensing purposes, all the engines are non-condensing; steam-power, therefore, is not

produced under the most economical conditions. There were originally three engines, each driving one generating dynamo; the Company has since added a fourth similar engine and dynamo in view of the extension of the line to Clapham, and to meet the requirements of the Board of Trade as to reserve power. The engines are of the vertical compound open type; the cylinders are side by side, 17 inches and 27 inches in diameter respectively, and 27 inches stroke. The fly-wheels are 14 feet in diameter, and carried between the cranks, which are of disk form. Both cylinders are steam-jacketed in the barrels, with high-pressure steam, and are fitted with slide-valves, with cut-off valves on both cylinders, controlled by the governors. The engines were built by Messrs. John Fowler & Co., of Leeds. They run at 100 revolutions per minute, and are each capable of indicating 400 HP., and drive the dynamos with link-leather belts, which are provided with jockey pulleys to allow of the distance between the engine and dynamo centres being reduced without unduly diminishing the area of contact on the driven pulleys.

It is frequently asserted that the use of a jockey-pulley involves considerable loss of power in friction. Consider the dynamical problem of a chain moving longitudinally with tension T and velocity V. Let it be subjected to a transverse disturbing force, acting at a fixed point and causing a deformation, which will generate two waves moving relatively to the diameter in opposite directions along its length with velocity $\sqrt{\frac{T}{m}}$, where m is the mass of unit length of the chain. If $V = \sqrt{\frac{T}{m}}$, one wave will move backwards with the velocity of the chain, and therefore remain fixed in space, and the other will travel onwards with velocity $2\sqrt{\frac{T}{m}}$. A link-belt may be considered as such a chain, and a jockey-pulley as the disturbing force. If the belt move with velocity $\sqrt{\frac{T}{m}}$ and the jockey-pulley be placed on its slack side, one wave will be stationary in space, tending to maintain the deformation of the belt round the jockey-pulley, and the other wave will move with twice the velocity of the belt towards the driven pulley, and will there be absorbed owing to the increased tension; thus the power absorbed is that required to maintain the single harmonic disturbance only.

The condition $V = \sqrt{\frac{T}{m}}$ is easily attained in practice. Let μ

be the coefficient of friction between the belt and the driven pulley, θ the angular measure of that part of the circumference of the driven pulley embraced by the belt, and T_2 and T_1 the tensions in the tight and slack sides of the belt respectively; then $\frac{T_2}{T_1} = e^{\mu\theta}$, where μ is the coefficient of friction between the pulley and the belt.

If the wave is stationary—

$$V = \sqrt{\frac{T_1}{m}} = \sqrt{\frac{T_2}{m\, e^{\mu\theta}}}.$$

Suppose μ is 0·2 and θ is 210°; then $V = \sqrt{\frac{T_2}{2{\cdot}08\, m}}$. Now a link-belt weighing 8 lbs. per foot is suitable for a working tension of 1,600 lbs.

Hence $$V = \sqrt{\frac{1{,}600 \times 32}{2{\cdot}08 \times 8}}$$ feet per second

= about 3,500 feet per minute, which is an ordinary speed for belting.

Generating Dynamos.

These are of the "Edison-Hopkinson" type, with bar armatures 19⅜ inches in diameter. The field-magnet coils are wound with both shunt and series coils, but the latter can be half short-circuited or entirely so, at will, by means of switches fixed on the dynamo. Each dynamo is capable of giving an output of 450 amperes at 500 volts, running at a speed of 500 revolutions per minute. The following are the electrical constants of the machines:—

	Ohms.
Resistance of armature	0·017
,, shunt coils	96·0
,, series coils	0·015

The electrical efficiency at full load is 96 per cent.

The weight of the armature is 37 cwt. The weight of the entire machine is 17 tons.

Careful independent experiments were made upon the efficiency of conversion showing that the frictional losses amounted to 2·7 per cent. of the full load. Hence the commercial full-load efficiency is 93·4 per cent.

Switch-boards.

The switch-board is arranged so that any of the four generators can be coupled to any of the four feeders either independently or in parallel, and that any fresh combination can be instantly effected

without interruption of the working. The electromotive force of each dynamo is measured by a Kelvin electrostatic multicellular voltmeter, and the current passing through each feeder is measured by an ampere-meter. The leakage of any part of the entire system of conductors when subjected to the full potential can be measured by a special low range ampere-meter. The feeders are provided with fusible cut-outs and quick-acting safety switches, which automatically throw a resistance into circuit if the current exceeds a certain amount; the object being to prevent injury if an accidental short circuit should take place on any part of the system.

Conductors.

From the switch-board there are four feeders, two of which are connected to the working conductors at Great Dover Street station, a distance of 12,800 feet from the generating station. The other two are coupled in parallel as far as Stockwell, and one is continued to the Oval, where it is connected to the working conductors at a distance of 4,330 feet from the generator-station. The cables, which were manufactured by the Fowler-Waring Company, and consist of a stranded core of 61-14 B.W.G., insulated and sheathed with lead, have an insulation resistance of not less than 500 megohms per mile. They are carried along the tunnels supported on the brackets carrying the hydraulic pipes (Fig. 1, Plate 5).

The working conductor is similar to that adopted by the Author for the Bessbrook and Newry Tramway, and consists of channel steel laid between the rails and carried on glass insulators fixed to alternate sleepers. The channel weighs 10 lbs. per lineal yard, and was rolled from mild ductile steel of special composition. The suitable proportions of carbon, silicon, and manganese for steel conductors have already been discussed by the Author.[1] By eliminating the silicon and slightly diminishing the carbon, a steel was obtained having a specific resistance as low as 0·0000105 ohm at 24° Centigrade, although the amount of manganese allowed was somewhat increased. This corresponds to a resistance of 0·0503 ohm per 1,000 feet. It will be observed that the level of the conductor is 1 inch below that of the rail-level. This necessitates arrangements for the lifting of the collectors over the crossing-rail at points. The conductor is broken on either side the crossing-rail and replaced by inclined planes of wood, up which the collectors slide till raised to a level of 1 inch above the crossing-rail, which passes through a gap left in the wooden runners. The collectors

[1] Minutes of Proceedings Inst. C.E., vol. xci. p. 202.

cross the gap at an angle, and are wide enough to bridge it. As each locomotive is provided with three collectors, the continuity of the circuit is never broken, as the leading collector makes contact with the steel conductor in advance of the break before the trailing collector leaves the conductor behind the break. The conductor is also divided into sections, and arranged so that any section can be coupled through automatic cut-outs to the adjacent sections or independently to the feeders. Thus any section can be isolated for the purpose of testing or repairs, and is automatically disconnected in case of any accident causing a short circuit to earth. The return circuit is through the rails, which are practically uninsulated. In such a system high insulation from the earth is neither aimed at nor required, provided the power lost in leakage is inconsiderable. The actual leakage on the entire system, consisting of dynamos, feeders and working conductors, tested at 500 volts pressure, is generally about $\frac{1}{2}$ ampere, corresponding with a loss of 0·3 horse-power, and rarely exceeds one ampere under the most unfavourable atmospheric conditions.

The use of the uninsulated rails as a return, although contact is made at an average depth of 60 feet below the ground surface, causes differences in earth potential, which are appreciable at considerable distances. Continuous observations of difference in the earth's potential between two points approximately north-east and south-west of Greenwich, and distant 3 miles from each other, and also between two points approximately north-west and south-east of Greenwich distant $2\frac{1}{2}$ miles apart, are recorded at the Royal Observatory. The former of these lines is parallel to the general course of the City and South London line at a distance of $4\frac{1}{2}$ miles, and the latter almost at right angles, the nearest point being $2\frac{1}{2}$ miles distant. It has been observed that along both lines differences of earth potential varying from a small fraction of a volt up to $\frac{1}{3}$ volt occur simultaneously with the working of the railway, and that the magnitude of the potential differences are approximately the same in both circuits. These observations show that the earth is of small value as a channel of return for large currents. As the disturbance is very erratic, and apparently has no definite direction, it is impossible to deduce any conclusions as to the resistance of the earth to the passage of large currents.[1]

Observations have also been made on the magnetic disturbances

[1] See a communication to *Nature*, by Mr. W. Ellis, with the permission of the Astronomer Royal. *Nature*, vol. xxiv. p. 129; also Annual Report of the Astronomer Royal, 1892, p. 15.

caused in the immediate vicinity of the railway, due to the electrical working. Professors Ayrton and Rucker erected a magnetometer in a house situated above the tunnels, and recorded readings at distances of 92 and 212 feet respectively from the line. Their observations are not expressed in absolute measure, but showed the disturbances to be considerable in comparison with the normal intensity of the earth's magnetic field, and that they were approximately inversely as the square of the distance from the line.[1] It is difficult to account for these magnetic disturbances, as the current flowing in the steel conductor would magnetize the iron of the tunnel circularly, and the tunnel itself would mask disturbances due to the passage of the motors. It would appear more probable that they arise from the return currents flowing through the earth outside the tunnels, which the observations at Greenwich show to be considerable. In this connection it may be noted that the tunnels do not in themselves form a complete metallic circuit, being broken by the brickwork at the stations, but at these points they are electrically connected by copper cables; the rails are also connected one to another by copper strips in addition to the ordinary fish plates.

Although the Author must admit that such disturbances, however insignificant, are inconvenient in the immediate neighbourhood of physical laboratories, they possess in themselves scientific interest; and in the case of the City and South London line they are not of sufficient magnitude to be of practical importance in connection with the working of the telegraph and telephone systems in the vicinity. In evidence before the Joint Committee, Mr. Preece stated, as the result of many experiments, that he had been unable to trace any disturbance of the Metropolitan telephones, or to the working of the telegraph lines, arising from the passage of the trains.

In the Report of the Joint Committee previously alluded to, the attention of the Board of Trade is drawn to a memorandum, prepared by Lord Kelvin, one of the members of the Committee, dealing with certain conditions with regard to the working potential and the position of the conductor to be observed in the case of the several Metropolitan Electric Railway schemes under their consideration. This memorandum recommends that if the working conductor is maintained at a pressure exceeding 500 volts, it should be carried overhead. Such was the original intention in the case of the City and South London line, but it was found to be impracticable on account of the exceedingly limited

[1] See a Paper read before the British Association, 1891.

space available for such a conductor above the carriages. This will be seen by reference to Fig. 1, Plate 5, but even the space there shown is still further reduced on the curves. With the considerably larger tunnels now projected (in no case less than 11 feet 6 inches in diameter), this difficulty will not occur. On the other hand, it should be observed that since the opening of the South London line there has not been a single instance of injury to the public from shock; and no complaint whatever has been made by the public of danger in this respect. Such also has been the experience on the Bessbrook line, where the potential is but little less, and the conductor is practically entirely unprotected. The Author ventures to think that mechanical facilities of treatment at points and crossings which an overhead conductor affords, is a stronger argument for its adoption than the public safety. The methods already described, of dealing with the conductor on the South London line at the points and crossings, have proved entirely satisfactory in practice; but exception may be justly taken to them on the ground that they are not universally applicable.

Locomotives, Figs. 3 and 4, Plate 5.

The essential feature in the design of the locomotives is that the armatures of the motors are built directly upon the axles, while the magnets are supported partly on the axle and partly on the frame. Thus gear of any description is entirely obviated, and the mechanism is reduced to its simplest elements. Although this principle of direct driving was suggested many years ago by the late Sir William Siemens, it has not previously been applied in practice. The field-magnets embrace the armature, leaving but an exceedingly narrow "gap," and are supported in part by brackets parallel to the axle with bearings upon it, and partly by links connecting the yoke to a cross-beam of the locomotive frame, thus permitting limited freedom of angular motion of the field round the axle, compensating for the rise and fall of the axle-boxes in the horn-blocks (Fig. 3). The weight of one axle with its wheels, axle-boxes and springs, and with the armature attached, is 24 cwts., and the part of the weight of the magnets resting on the axle is 10 cwts., whence the total dead weight on each axle is 34 cwts. In ordinary locomotive practice, where the speeds are much greater, and the permanent way more elastic, the dead weight, including wheels, cranked axle, axle-boxes, springs, eccentrics, and the large ends of the connecting-rods, is much greater, and there appears to be no reason why the

limit allowed in the case of ordinary steam-motors is not permissible for electric-motors; in fact, the perfect freedom of the axle laterally, and the fact that the two driving-axles are not coupled, but have entire freedom of motion relatively, together with the consideration that the forces acting on the axle, apart from its weight, constitute a pure couple without any thrust, make it probable that a much higher limit of dead weight may be safely allowed in a system of electric-motors, so applied, than in the case of ordinary steam locomotives. It has, however, been contended that the vibration must have an injurious effect upon the armature. In reply, it is sufficient to point out that the experience of two years' working has not revealed a single case of deterioration of an armature, which can be attributed to this cause; and the bearings supporting the field-magnets have shown no signs of undue wear.

Geared traction-motors have the following advantages, real or apparent, over direct-acting motors:—

(1) The introduction of gear allows the use of a motor running at a much higher speed than the axle, consequently the motor itself is of less weight, occupies less space, and is less costly.

(2) The weight of the motor can be taken almost entirely on the springs instead of acting directly on the axle.

(3) The motor running at a higher speed is in itself, when considered irrespective of the gear, of higher efficiency.

(4) The dimensions of the motor are not directly limited by the gauge of the line and the diameter of the driving-wheels.

The first argument has much force in tramway-work. Here reduction in weight and in bulk are of the utmost importance. As the whole weight of the car is available for adhesion, any reduction in weight is clear gain. Again the motor must necessarily be placed entirely beneath the floor, and must often be combined with a bogie construction; hence reduction in the dimensions of the motor is frequently of primary importance. It is no doubt these two considerations, combined with reduction in first cost, which have led to some form of gear being almost universally adopted on the American tram-lines; but it is interesting in this connection to note that the leading American construction-companies have abandoned motors with double-reduction gear for single-reduction gear; thus proving, as the result of extended experience, that the wear and tear and loss of efficiency in gear more than counterbalances the advantages of reduced weight and bulk, when carried beyond certain limits. On the other hand, in the case of independent locomotives, the

consideration of weight in general entirely loses its force; as the natural weight of the locomotive, whatever form of motor be adopted, is not more than sufficient for adhesion, and the form of the motor is not restricted by consideration of clear floor space.

The second argument has already been dealt with in comparing the dead weight on the axles on the South London line with ordinary locomotive practice; but here, again, it is of interest to observe that, although with the system of gear adopted in America it is quite feasible to remove the dead weight almost entirely from the axle, it is not found necessary to do so. The Short Company of Cleveland, Ohio, have recently worked out devices for spring-connections between the axle and the armature, while still retaining the principle of direct driving. Their system has already been adopted on a number of lines with satisfactory results. The interposition of springs may be advantageous for rough roads, but it yet remains to be proved by exhaustive trial that the simpler form, with the armature keyed directly on the axle, is unsuitable even for ordinary street-tramways.

A complete discussion of the third argument involves a determination of efficiency of the different systems of gear available, since although the high speed motor is in itself more efficient than the slow speed, there is loss of power in the gear, which may more than compensate for the saving in the motor. Consider a 20-HP. direct-acting motor with driving-wheels 30 inches in diameter. At 20 miles per hour the number of revolutions will be 224 per minute; the efficiency of a motor at this speed will not in general exceed 88 per cent., and the weight will be about 50 cwts. If such a motor acted through gear reducing the speed in the ratio of 3 : 1, the number of revolutions corresponding to a speed of 20 miles per hour is 672 per minute; at this speed the motor should be of not less than 96 per cent. efficiency, and will weigh with its gear about 30 cwt.; hence, if the efficiency of the gear is less than 96 per cent., there is no gain in the total efficiency. The Author has no data available as to the actual efficiency of the gear as realized in American practice, but it is not probable that the frictional losses in actual work can be brought within 10 per cent.; at least such is the result of his own experience both with spur-gear and chain-gear. Both Mr. Reckenzaun and Mr. Holroyd Smith have strongly advocated the adoption of worm-gear, and the former has made experiments on the efficiency obtainable by it, but his best results show an efficiency of less than 90 per cent.

As regards the fourth argument in favour of other than direct-

acting motors, it is sufficient to remark that the limits imposed on the dimensions of the latter have proved no bar to the construction of the 100-HP. locomotives on the South London line. Whether such will be the case when locomotives of 300 to 400 HP. are required, it is beyond the limits of the present Paper to discuss; but the difficulty, if such it prove to be, can be met by increasing the number of driving-axles, or by the adoption of a different form of field-magnets—allowing the armature to be increased in diameter to the full diameter of the wheels, less what may be necessary for clearance.

In order to obtain experience of the relative advantages of geared and direct-acting locomotives under the same conditions, one geared locomotive was built for the South London line. Though of the same power as the others, and yielding good results in experimental running, its relative value may be best gauged by the fact that it was soon relegated to the work of a stand-by engine, while the regular work of the line was undertaken entirely by the direct-acting type.

To sum up, it appears that the balance of argument is in favour of direct-acting motors for both locomotives and street-tramway work; but that, with regard to the latter, experience is yet insufficient to warrant the formation of a final opinion.

The two motors on each locomotive on the South London line are each capable of developing 50 HP. at a speed of 25 miles per hour, corresponding to 310 revolutions of the axle per minute. The magnets are of the "Edison-Hopkinson" form, and series-wound; and the armatures are of the Gramme ring type. The resistance of the magnet coils of each motor is 0·087 ohm, and of the armature 0·3 ohm. The two motors are connected electrically in series. The current from the conductor is conveyed from sliding collectors through a fusible cut-out and main switch to a rheostat-switch for inserting resistance at starting; thence it passes through a reversing switch to the motors, and finally through the axle-boxes and wheels to the rails of the permanent way. The motor-magnets are proportioned relatively to the armature precisely as in a dynamo, and are wound so as to be nearly saturated with the mean working current. Above this point, the curve of tractive force and current is approximately a straight line, giving a tractive force of 1,180 lbs. with 100 amperes, and a maximum of 3,000 lbs. with 226 amperes. The trains are fitted with the Westinghouse continuous automatic brake, applied, however, in a novel manner suggested by Mr. Greathead. In place of a pump working continuously on the

locomotive, the latter is provided with two reservoirs placed under the curved side-plates of the cab, each of about 8·25 cubic feet capacity. At the end of each double journey these are charged with air, at 80 lbs. pressure, from a small reservoir erected at Stockwell, the pressure in which is maintained by two small pumps in the engine-house. The reservoirs on the locomotives are of sufficient capacity to provide for about 30 stops from full speed. This system has proved both convenient in practice, and economical, the total amount of steam required for the brakes being about 1·5 per cent. of the entire consumption. In addition to the Westinghouse brake, a powerful hand-screw brake is fitted on each locomotive. The locomotives and carriages are lighted with glow-lamps, supplied direct from the conductor, an arrangement which has the merits of simplicity and cheapness, but is open to the objection that the light is necessarily subject to some fluctuation owing to the variations of the electromotive force of the conductor.

The following are the leading dimensions of the locomotives; of which Fig. 3, Plate 5, shows a longitudinal section, and Fig. 4 a perspective view:—

	Feet.	In.
Length over central buffers	14	0
„ „ cab	10	0
Wheel base	6	0
Diameter of wheels	2	3
Gauge	4	8½
Extreme width of cab	6	3
Height, rail-level to floor-plate	2	5¼
„ floor-plate to roof	6	0
Weight of entire locomotive, 10 tons 7 cwt.		
„ „ motors only, with wheels and axles, 6 tons.		

Of the 14 locomotives first supplied, 13 are of the direct-acting type and one is a geared locomotive. Since the opening of the line two additional locomotives have been furnished by Messrs. Siemens Brothers. In these the general features of the design described have been followed, but the armatures are of drum in place of the Gramme type. Mr. Alexander Siemens described the working of these locomotives before the British Association, in 1892, and gave a series of curves showing the relation between the speed, current and electromotive force at short intervals as observed on several runs under varied conditions.

The whole of the electrical plant was constructed by Messrs. Mather and Platt, for whom Dr. John Hopkinson acted as consulting engineer, and Mr. G. Annesley Grindle as resident engineer; Mr. C. E. Spagnoletti acting as consulting electrician to the Company.

Efficiency.

The discussion of the efficiency of an electric railway-system may be considered under three heads:—

1. The production of electric power.
2. The distribution of electric power.
3. The re-conversion of electrical into mechanical power.

(1) It is unnecessary to enter into the details of the efficiency of the steam production, as the installation in this respect presents no distinctive features. The daily consumption of water for all power purposes is about 330,000 lbs., which is evaporated by the combustion of 21 tons of north country slack, including in this the fuel required for starting and banking the fires, *i.e.*, 7 lbs. of steam at 140 lbs. pressure per pound of fuel, a result which may be considered as normal for an installation working under varying loads, and not provided with an economiser. The division of the steam-consumption between the electric generating engines, the hydraulic engines, and other small engines employed on the works cannot be accurately determined, as all are supplied from the same range of steam pipes; but sufficient data have been obtained to show that from 60 to 67 per cent. of the total steam produced is absorbed by the electric generator engines; representing a daily consumption of about 14 tons of north country coal. No direct measurements have been made of the fuel-consumption per indicated HP.-hour of the engines, but a rough approximation can be made by calculating the average indicated HP. taken through the day from the average electrical output of the generating dynamos. This calculation shows that about 230 HP. is the average load on each engine, *i.e.*, a little more than one-half of their maximum load. On this basis the water-consumption per indicated HP.-hour is 27·5 lbs. Probably no tests have been previously made on engines working under the abnormal conditions of a load constantly varying at very short intervals from one-fourth, or a less fraction, of the full load, up to the maximum, and averaging a little more than one-half the maximum. It is not, therefore, possible to institute a comparison between this result and others; but it has been shown that with a Willans central-valve engine, which realises as high an efficiency as 18·25 lbs. of water per indicated HP.-hour, non-condensing, at full load, the efficiency is reduced to 22 lbs. at half load and 36 lbs. at one-fifth load.[1]

The efficiency of the engines and dynamos combined was ascer-

[1] Minutes of Proceedings Inst. C.E., vol. cvi. p. 67.

tained by indicating the engines and measuring the electrical output at the terminals of the dynamos, when working on a steady load. These experiments show an average efficiency of available electrical HP. against indicated HP. of—at full load, 78 per cent.; at three-quarters load, 70 per cent.; at half-load, 65 per cent.

Somewhat higher efficiencies than these are constantly obtained with high-speed engines driving dynamos direct without the intervention of belting. Mr. Crompton has stated the efficiency of the combination of an Edison-Hopkinson dynamo driven by a Willans engine to be 86·2 per cent. at full load, and 77·8 per cent. at half load; and that of a Crompton dynamo with the same engine 85·8 per cent. at full load, and 78·1 per cent. at half load;[1] the dynamos being in both cases of approximately the same efficiency as the generator-dynamos. The loss is therefore in the greater engine friction and in the belt. It is, however, doubtful, or at any rate, remains to be proved, whether a high-speed engine driving direct will give as relatively satisfactory results, without undue wear and tear and liability to accident, when working under the abnormal conditions of load obtaining in traction work.

The daily consumption of electrical energy is about 3,700 Board of Trade units, which are produced from the combustion of 14 tons of coal, or 8·4 lbs. of north country coal per Board of Trade unit, corresponding to about 7·5 lbs. of Welsh coal per unit.

The diagrams, *Figs. 1* and *2*, pages 226 and 227, show the quantity of current passing through the feeders at consecutive intervals, when seven and eight trains respectively are running. A momentary inspection of these shows at once the magnitude and rapidity of the variations in load, which make the realization of a high load-factor impossible. If an efficient accumulator, capable of working as a regulator under these conditions, could be introduced, it would be possible to reduce the capacity of the generating-plant by at least 40 per cent., and at the same time considerably increase its efficiency.

(2) The efficiency of distribution is not of general interest, as it depends solely upon the resistance of the conductors. It is sufficient to state that the average full load loss in the long feeders running to Great Dover Street is 5·7 per cent., and in the short feeders 3·5 per cent. Thus the total loss in the feeders is 9·2 per cent. The distant feeders are usually coupled to a generator-dynamo working full-compound, while the home-feeders are connected to a generator working half-compound, thus compensating for the loss of electromotive force

[1] Minutes of Proceedings Inst. C.E., vol. cvi. p. 31.

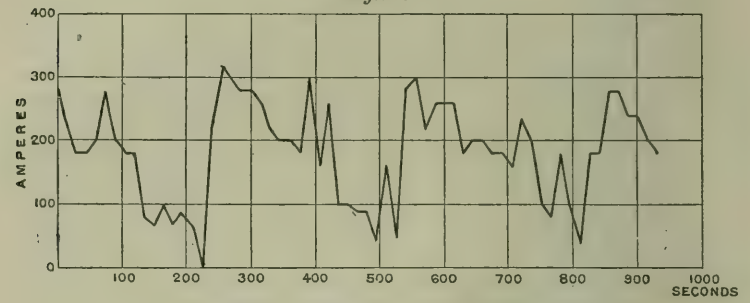
in the feeders. The loss in the working conductors can only be estimated from the average current in each section and the known resistance. It probably does not exceed 1 per cent., making the total loss in distribution a little more than 10 per cent. of the total electrical power generated. This represents a daily expenditure of fuel of about 1½ ton of north country coal, which is almost the exact equivalent of the interest on £7,000, the actual cost of the conductors. Thus the continuing cost of distribution is a minimum.

(3) The efficiency of the motors with known electromotive force and current is easily determined, but it is of greater interest to ascertain the average efficiency of the locomotives as a whole, while working under the constantly varying conditions of speed, load, and electromotive force. By a statistical method this may be ascertained with fair accuracy. Observations were made at intervals of ten seconds on locomotives with varying loads running in the regular service to ascertain the current and speed at each interval. These results were plotted in two series of curves, with time as abscissa and current and speed as ordinates. Since the counter-electromotive force[1] of the motors depends only upon the current and speed, and can be determined directly from the characteristic curves of the motors, when these elements are known; a second series of curves can be drawn with the counter-electromotive force as ordinates and time as abscissa. These can be integrated to give the average counter-electromotive force. Simultaneous observations were made on the electromotive force at the generator dynamos, and were in like manner integrated to give the average electromotive force. The ratio of the average counter-electromotive force to the average electromotive force at the generators is the electrical efficiency of the entire system. The results of a number of such observations, made at different times with train-loads varying from 35 to 40 tons, are in close accordance, and show the electrical efficiency of the entire system to be about 62 per cent. It has already been shown that the loss in the conductors is a little over 10 per cent., hence the average electrical efficiency of the locomotives is 70 per cent. In the 30 per cent. lost, the power absorbed in the starting resistance

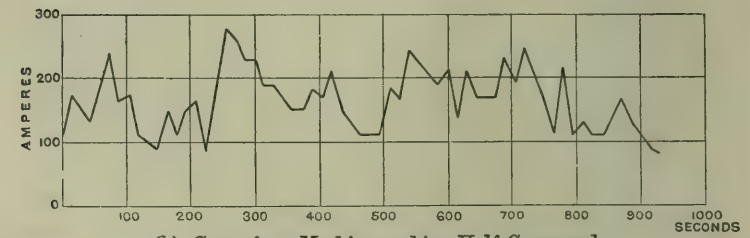
[1] The terms "counter-electromotive force" or "back-electromotive force" are not satisfactory, but are used in default of any authoritative nomenclature. Let E be the electromotive force at the terminal of a series wound generator or motor, R the resistance of magnets and armature, and C the current; then $E + RC$ is commonly known as the "true electromotive force" for a generator, and $-RC$ as the "counter-" or "back-electromotive force" for a motor.

is included, and probably accounts for about one-half. Various devices have been proposed in order to reduce this loss. Dr. John Hopkinson, in 1881, patented a method of throwing the two motors into series at starting, and into parallel circuit as the speed increases; and others have suggested varying the effective convolutions on the magnets; but such devices, although reducing the loss, do not entirely obviate the need of starting-resistances. Moreover, they involve complications in the switching-gear, and the simplicity of the simple resistance appeared to the Author to more than counterbalance any small increase in efficiency.

Figs. 1.



(a) *Curve from Machine working Full Compound.*



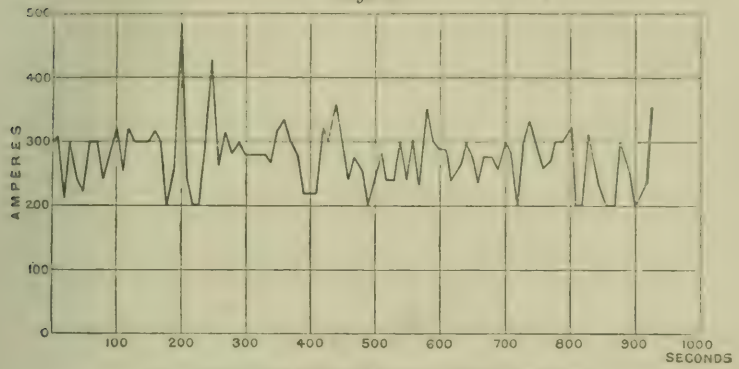
(b) *Curve from Machine working Half Compound.*

Seven Trains and Two Shunting Locomotives.

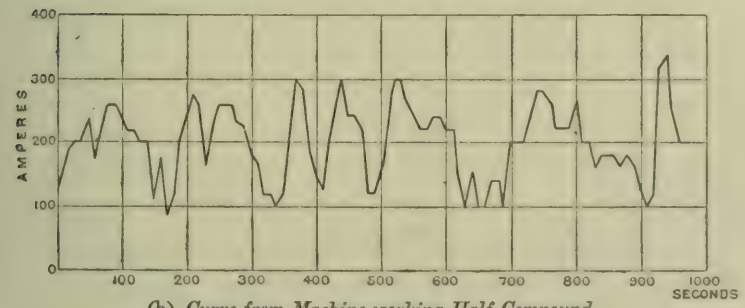
These results, obtained in actual practice, fully substantiate the estimates of efficiency given in evidence before the Committee on The Central London Railway Bill by Sir Benjamin Baker and Dr. John Hopkinson. The former stated, before the Select Committee of the House of Lords, in 1890, that the efficiency as between indicated power and effective power on the rails would be from 50 to 60 per cent., assuming that the load was fairly averaged, so that the generating-plant worked at approximately full load, and the motors at their proper efficiency. This result would have been attained on the City and South London line if the service of 20 trains per hour, as originally contemplated,

had been carried out, and the loaded trains had not exceeded their specified weight. Owing to the actual weight of the trains being over 40 tons, arising from the fact that the carriages weigh over 7 tons each, instead of $4\frac{1}{4}$ tons, as specified at the time the electrical plant was designed, the service has been reduced to fourteen or sixteen trains per hour, and the motors are much overloaded, thus working at an efficiency materially less than they would do, if worked with the loads for which they were constructed. From the

Figs. 2.



(a) *Curve from Machine working Full Compound.*



(b) *Curve from Machine working Half Compound.*

Eight Trains and Two Shunting Locomotives.

foregoing analysis, it appears that the efficiency of the generating-plant would have been 78 per cent., and the locomotives would have been of at least 80 per cent. average efficiency, including all losses in resistances and otherwise. Taking the loss in the conductors as usually observed, the total efficiency as between indicated power and effective power would thus have been

$$\frac{78}{100} \times \frac{80}{100} \times \frac{90}{100} = 56{\cdot}2 \text{ per cent.}$$

Again, Dr. John Hopkinson, before the Select Committee of the House of Commons on the same Bill, estimated, under similar conditions, the loss between the power actually absorbed by the generating dynamos and the effective power of the locomotives as 33 per cent. With generators as efficient as those of the Edison-Hopkinson type employed for the South London line, the efficiency between electrical power delivered from the dynamos and the power absorbed by them is 93 per cent.; hence the efficiency of the entire system as defined would be $\frac{93}{100} \times \frac{90}{100} \times \frac{80}{100} = 67$ per cent., which is in exact accordance with the evidence quoted.

Although the analysis of the efficiency of the several component parts of the system may be of interest to the engineer engaged in the design of railway plant, the final question remains: what is the expenditure of fuel per mile run?

On the South London line, the average speed of working, including intermediate stoppages, is 11·5 miles per hour, and of actual running between stations 13·5 miles per hour. The maximum speed attained between stations varies from 20 to 25 miles per hour. The weight of a normally loaded train is 40 tons. The daily mileage for the half-year ending June 30, 1892, was 1,120; hence the consumption of fuel per train-mile is 28 lbs. of north country coal, equivalent to about 25 lbs. of Welsh coal. This result compares very favourably with the best results of American tramway practice, having regard to relative loads and speeds.

Cost of Working.

The following Table, extracted from the half-yearly returns of the Company, shows the total cost of locomotive power, and the train-mileage from which the cost per train-mile is deduced. It will be seen that for the half-year ending December 31st, 1892, it is 7·1*d.* per mile. Whilst there is a continued increase in the mileage, the working expenses show a continuous decrease, a result due to the management of Messrs. Basil Mott and T. C. Jenkin, who are respectively engineer and general manager to the company.

The contractors' guarantee of working cost was 3·5*d.* per train-mile, for a service of 14,800 train-miles per week, and 6·3*d.* for a service of 8,247 miles per week, as actually run. This figure included the entire cost of running the generating-plant, *i.e.*, supervision, fuel, stores, wages, and repairs; also the cost of maintenance of the conductors and locomotives, but was exclusive of the drivers' wages. These latter at present average about 2*d.*

per train-mile, hence the actual cost of working, exclusive of drivers' wages, is 5·1*d.* per train-mile, against 6·3*d.* per train-mile

	Half-Year ending			
	June 30, 1891.	Dec. 31, 1891.	June 30, 1892.	Dec. 31, 1892.
Salaries, offices, expenses, and superintendence	£ s. d. 65 12 0	£ s. d. 100 8 4	£ s. d. 192 3 4	£ s. d. 148 11 8
Running Expenses.				
Wages connected with working the generating and locomotive engines	3,408 16 10	3,258 1 9	2,720 8 1	2,788 12 6
Fuel	2,054 4 10	1,985 18 6	1,970 19 4	2,172 0 9
Water and gas	251 5 6	263 9 6	253 11 0	252 9 9
Oil and stores	434 2 1	371 18 1	415 3 4	457 6 11
Repairs and Renewals.				
Wages	150 0 0	26 3 9	205 0 0	240 0 0
Materials	223 2 1	193 13 0	277 17 10	289 3 1
Total	6,587 3 4	6,199 12 11	6,035 2 11	6,348 4 8
Total of running expenses only	6,148 9 3	5,879 7 10	5,360 1 9	5,670 9 11
Train-mileage	174,435	188,666	188,944	214,417
Total cost of locomotive and generating power per train-mile	9·1*d.*	7·8*d.*	7·7*d.*	7·1*d.*
Cost of running expenses per train-mile	8·4*d.*	7·0*d.*	6·7*d.*	6·3*d.*

guaranteed. Thus the actual cost is less, by 20 per cent., than the contractors' guarantee, although the trains are 30 per cent. heavier than the weight upon which their guarantee was founded.

Since the opening of the line two years ago, the locomotives have run more than 820,000 miles, and have provided for a traffic of over 12,000,000 passengers; and the yearly mileage of each locomotive in regular running exceeds 30,000 miles. The growing popularity of this new means of locomotion is abundantly proved by the steadily-continued increase in the number of passengers and traffic receipts.

The Paper is accompanied by six tracings, from which Plate 5 and the *Figs.* in the text have been prepared.

[Appendix.

APPENDIX.

Bessbrook and Newry Electric Tramway.

—	Tonnage.	Mileage.	Passengers.
1886	12,238	19,872	97,636
1887	13,464	19,212	81,275
1888	14,928	20,376	85,450
1889	17,055	20,424	85,978
1890	16,173	20,478	92,447
1891	15,852	21,468	94,165
Total	89,710	121,830	536,951

Cost of haulage for year 1891.

	£	s.	d.
Wages (drivers, guards, and dynamo engineer)	123	12	6
Maintenance and repairs of electrical machinery, materials	60	6	4
" " " wages	23	18	9
Oil, grease, and waste	9	6	2
Water rent	128	11	0
Total	£345	14	9

Train-mileage, 21,468.
Hence cost per train-mile, 3·94*d.*

Electrical Tramways in the United Kingdom.

Date of Opening.	—	Miles.	System.	—
1883	Portrush and Giant Causeway	8	Side conductor	Water-power.
1883	Brighton Beach	1	Rails	Gas-engine.
1885	Bessbrook and Newry Tramway	3¼	Central conductor	Water-power.
1886	Ryde Pier	½	Side conductor	Gas-engine.
1886	Blackpool	2	Conduit	Steam.
1889	Carstairs	1¼	Side conductors	Water-power.
1890	Birmingham	3	Accumulator	
1891	Southend Pier	¾	Central conductor	Steam.
1891	Guernsey	2¾	Overhead conductor	"
1891	Leeds	3¼	" "	"
1893	South Staffordshire	7½	" "	"

Discussion.

Mr. Harrison Hayter, President, said that there was little doubt from what they saw going on around them, from the success already achieved, and from the inventions and improvements continually taking place, that the use of electricity as a motive power was on the increase, and would continue to increase. The subject, therefore, was one of special interest to the engineer; and it was opportune that the Institution at the present moment should have such a Paper brought before it. He would notice that the subject before them was the working, not the construction, of electrical railways. He mentioned that circumstance because, before the Session was over, the Institution was promised a Paper on the construction of the City and South London Electrical Railway by Mr. Greathead, and the members would then have an opportunity of discussing the construction of such lines. At present the discussion therefore would be confined to the working of electrical railways, unless indeed there should be any detail of construction that might have to be referred to as bearing on the working. The Author had paid considerable attention to the subject, and had been good enough to give them the results of his experience. It was therefore hardly necessary to propose, although he would do so in compliance with established usage, a vote of thanks to the Author for his practical and useful Paper. Mr. Hayter.

Dr. Edward Hopkinson said that there were three or four points not properly forming part of the subject matter of the Paper, which were incidental thereto, and to which he should like briefly to refer. One of the first problems to be solved before considering the question of the power which ought to be provided for working such a railway, was the determination of the air-resistance to a train moving rapidly through such a tunnel. He had not discussed the question in the Paper, because the general problem of the motion of air in tubes had been fully investigated by Professor Osborne Reynolds, Professor Unwin, and others; but he might say that the air-resistance was a by no means negligible portion of the total resistance to the motion of the train. It would be seen from the diagrams that more than half the section of the tunnel was taken up by the train; consequently the air must either be pushed in front, or must pass to the back of the train through the restricted passage; in the latter case it would Dr. Hopkinson.

Dr. Hopkinson. be retarded by the skin friction along the train and by the friction against the rough sides of the tunnel. That the velocity of the entire mass of air in the tunnel would be small could be easily proved and had been confirmed by observation. Hence the train had to maintain the motion of the air past itself in, as it were, a rough tube of less than half the section of the tunnel, consequently the resistance would be considerably more than four times what it would be were the train moving in the open. Another point which was entirely incidental, but which he thought was of some interest, was the question of the theory of the jockey-pulley. He knew it was a common impression amongst engineers, that the use of a jockey-pulley meant much loss of power in friction; but he thought that was not necessarily so. Taking the case of a stretched chain, which a link belt practically was, at rest, if they gave it a deformation transversely—say, a blow at right-angles to the chain—two waves would travel along the chain, one backward and the other forward. The velocity of those waves would depend only upon the tension of the chain and upon the mass of a unit length; in fact, the velocity was the square root of the tension divided by the mass of a unit length. Instead of the chain being fixed, suppose it to move: in the case of the belt it was moving in a direction round the driven pulley, and so back to the fly-wheel. Clearly, if the velocity of the belt was the same as the velocity of the wave caused by any transverse disturbance, one of the waves travelling against the belt would remain fixed in space, and the other would travel with double the velocity of the belt and come on to the pulley, and, by reason of the greater tension on the belt round the pulley, would be absorbed or reflected back. They would then have this condition of things: assuming the velocity of the belt to be equal to $\sqrt{\frac{T}{M}}$, if the belt were subjected to a disturbance transversely—which was exactly the action of the jockey-pulley—the disturbance would remain stationary; so that the jockey-pulley had nothing more to do than to maintain that single harmonic vibration. Of course that meant the loss of a very small amount of power. If the velocity of the belt moving in that way was not equal to the velocity of the wave, then there would be a number of vibrations set up, and the loss of power might be considerable. He had found that in some instances this condition could be approximately fulfilled. In dealing with the problem, the force of gravity on the belt must be considered. If this could be neglected, what had been said as applying to the jockey-pulley

would apply also to the driven pulley, and the belt would not drive at all. The third point he wished to mention was the question of separate locomotives, in regard to which he desired to anticipate some criticism which was sure to be raised in the discussion, because possibly if he then referred to it it might save time afterwards. It was constantly said that one great advantage of electrical propulsion was that the number of driving-axles could be increased to a large extent, and that the proper way to apply it was to put a motor upon each axle of the train, and by that means save dead weight. That advantage was great on lines with exceptionally steep grades, but in none of the practical cases with which he had had to deal had he found that there had been any material advantage in subdividing the motive power in that way. Taking the case of the City and South London Railway, the average total weight of a train might be said to be about 40 tons, and the weight of the locomotive 10 tons. Of that 10 tons the motors and electrical gear absorbed 6 tons. The motors had to be somewhere, it was therefore impossible to save the 6 tons, so that the extreme saving would be the 4 tons of the locomotive frame. But if the motors were subdivided into smaller ones, the weight would necessarily be increased. Again, supposing they were put upon the bogies, the bogies themselves would have to be considerably strengthened, and their weight would be increased, so that probably the extreme saving would be from 1 to 2 tons, out of a total of 40 tons, or from 2 to 5 per cent. That saving was very small compared with the great advantage of having the motors on a separate vehicle, and immediately under control and proper inspection. Since he had written the Paper a very important addition had been made to electric traction, viz., the Liverpool Overhead Railway. He did not refer to it, because, at the time of writing, as far as he was aware, there had been no running on the line, and now, although it had been inaugurated under high auspices, it had not yet been opened for public traffic, but he hoped, as some gentlemen intimately connected with the railway were present, they would give the members some details of the construction of the electrical plant on that line. There was another point to which he wished to draw attention, which was not included in the Paper, because he had only received the figures since the Paper was written, and he was greatly indebted for them to Mr. Jenkin and Mr. B. Mott, officials of the Company. They were given in Table I. He had been able to separate the cost of the generator-station working, that was, the cost of the production of electricity, from the cost of

Dr. Hopkinson

Mr. Hopkinson. locomotive power, or of utilizing the electric current and reconverting it into mechanical power. In that Table he had excluded office expenses, and had simply considered the wages, fuel, water, gas, oil, stores, and repairs, given in pence per train-mile. It would be seen that the total cost of the generating power was 4·59*d.* per train-mile. Knowing the total amount of electrical energy produced, they could obtain the cost per Board of Trade unit, which was a figure of great interest to all who had anything to do with electrical engineering; and he thought it was a striking result that in the first railway of any magnitude the cost of the Board of Trade unit had been reduced to a smaller figure than in any electric station in England, and, as far as he knew, in the world, with the exception of Bradford, where the cost was 1·41*d.* against 1·56*d.*, but at Bradford they had the advantage of exceedingly cheap coal, and perhaps of cheaper labour, than was available in London. Taking another case, that of the St. James's and Pall Mall Electric Lighting Company, one of the most successful central lighting stations, the cost per unit in 1892 was, he believed, 2·26*d.* The lower part of the Table gave the cost of the locomotive working. He did not know that there was much to call attention to, except the fact that in both one and the other the item of repairs was small, and the item for wages was also small, which was of course entirely due to the excellent management of the line.

TABLE I.

City and South London Railway, half-year ending December 31st, 1892—

Train mileage	214,417
Number of passengers	3,317,602

Cost of working generator-station, excluding office expenses—

	£	*d.*	
Wages	1,012	1·12	per train-mile.
Fuel	2,172	2·42	,, ,,
Water and gas . .	252	0·28	,, ,,
Oil and stores . .	368	0·41	,, ,,
Repairs and renewals	321	0·36	,, ,,
	4,125	4·59	,, ,,

Equivalent to 1·56*d.* per Board of Trade unit.

Cost of locomotive working, excluding office expenses—

	£	*d.*	
Wages	1,776	1·98	per train-mile.
Oil and stores . .	89	0·10	,, ,,
Repairs and renewals	208	0·23	,, ,,
	2,073	2·31	,, ,,

Mr. A. Reckenzaun said that engineers and others interested in electric traction, himself included, were constantly referring to the progress made in the United States in electrical traction. Dr. Hopkinson had also introduced the subject of the statistics of electrical traction in that country; and had stated that in America there were upwards of 4,000 miles of electrical railways as compared with 33½ in Great Britain; or, including Liverpool, 40 miles. Probably few engineers on this side of the Atlantic were aware of the fact that electrical traction in the United States was encouraged, primarily, by estate agents and speculators. The earlier tramways and railways were suburban lines; and they were constructed before there were roads or houses, for the principal purpose of developing certain estates where people would not live unless there were roads, and unless there was rapid transit. The estates were worth very little—probably they were only agricultural or waste land—but they had been developed by those means; and the profit derived by the speculation had, in many instances, more than paid for the electrical railway. An advantage which the Americans enjoyed was that they required no Act of Parliament to build a line; they merely had to ask the local authorities for permission to run a line through the streets, and in ninety-nine cases out of a hundred they got permission immediately; and perhaps three months after the "franchise" was obtained, the line was in operation. In that way, those 4,000 miles of electrical tramways had been established, the majority of which were new lines. Many of the lines, originally constructed for horses, had been converted into electrical lines; but there, also, the financier had done the principal part of the business. The tramway companies were not in a position to purchase the plant necessary for increasing the quickness of their service; a trust company was therefore established, which bought up the horse-tramways, or guaranteed certain dividends on bonds. By that means, capital was advanced for the establishment of electrical lines, and for the conversion of horse-lines into electrical ones. On this side the Atlantic, and particularly in Great Britain, as the Author had pointed out, progress had been very slow, although Great Britain was years ahead of the United States in the practical application of electricity to tramway working, as could be seen by the Appendix to the Paper. The Author had shown that the Portrush line was opened in 1883, the Brighton Beach line in the same year, the Bessbrook line in 1885, and several others in 1886; whereas the "boom" in the United States did not commence until 1887, but it had rapidly progressed ever since.

Mr. Reckenzaun.

Mr. Reckenzaun.

In Great Britain, before a horse-line could be turned into an electrical one, it was necessary to get an Act of Parliament. The old tramway companies had an Act of Parliament which did not contain a clause permitting the use of electricity as a motive power; but the new Acts passed within seven or eight years had such a clause. This, however, had been mutilated by the influence of the National Telephone Company, so that the lines might be constructed in such a manner as not to interfere with the single-wire telephone, which would make the electric tramway system in use in America of single overhead conductors an impossibility. Then, besides getting the Act of Parliament, the local authorities had to be consulted, and the public in general seemed to be opposed to the use of overhead conductors. The Americans did not object to numerous poles in the streets. There were poles for telephones, poles for electric wires, telegraph poles, and poles for electric railways; indeed, some of the finest streets were nothing but avenues of ugly poles. In this country such things would not be permitted; overhead conductors were evidently at present unpopular. Then many of the British tramway companies were poor, and, even if they had an Act of Parliament and obtained permission to run overhead conductors, they had not the money to buy the plant with; and if they increased their capital in proportion, they probably would not be able to pay a dividend. They had all those difficulties to contend with, and therefore electrical traction made but very slow progress. Referring to the more technical portions of the Paper, he observed that the Author gave credit to the late Sir William Siemens for suggesting the method of putting the armature direct upon the axle of the locomotive or car. Nine or ten years ago Mr. Reckenzaun was connected with an electrical railway problem which involved locomotives of considerable power, for which Messrs. Siemens Brothers were the designers. The armature, as in the case mentioned, was placed upon the axles. Messrs. Mather and Platt were the first to have the opportunity of applying that in practice, and great credit was due to them for showing that it could be successfully done. It was his opinion, and that of many others, that an armature which consisted of more than a thousand distinct pieces of metal and insulation bolted together might not be able to stand the strain of the acute vibrations of an axle running at such a speed as those locomotives on ordinary rails. Two years' working, as the Author had pointed out, had shown that there was no fear that the armature would suffer from that cause. The Author had referred to the

amount of HP. that might be put upon a single axle, and had stated that he had succeeded in getting 100 HP. on two axles. It was a question whether more than that power should be put upon an axle on a railway 4 feet 8½ inches gauge, and he had some doubts whether it could be done. The General Electric Company of America had built a locomotive of 600 calculated HP. for the Baltimore and Ohio line. Although they used multipolar motors and large driving wheels, they were obliged to make six driving-axles, so that they could get that amount of power on the locomotive. As they increased the power they must also increase the number of axles. In connection with the question of 100 HP. of the locomotive, he wished to ask the Author how he arrived at it. He had stated that "the two motors on each locomotive on the South London line are each capable of developing 50 HP. at a speed of 25 miles per hour, corresponding to 310 revolutions of the axle per minute." Now 100 electrical HP. at a pressure of 500 volts meant 150 amperes. With 150 amperes the armature would be revolved at a very low speed. This current would only be used at starting, and at that moment the mechanical horse-power given off was nil, or very small indeed; so that if 150 amperes at a pressure of 500 volts were used at starting, probably 90 or 80 or 70 per cent. was wasted in heating the wire. Thus, at the moment of starting the locomotive could not give 100 mechanical HP. With regard to the 25 miles per hour, as the revolutions of the armature increased, so the counter-electromotive force increased and the current decreased; consequently 25 miles per hour could not give 100 HP., or even 50 HP. He had calculated that if it gave 100 HP. at 25 miles per hour and 40 tons load, the coefficient of traction would be as much as 37½ lbs. per ton, which was enormous. He believed that the Author was wrong in asserting that his locomotives were capable of giving 100 HP. either at full speed or at low speed. As to the efficiency of the motor, the Author, referring to the reconversion of electrical into mechanical energy, had stated, "The efficiency of the motors with known electromotive force and current is easily determined, but it is of greater interest to ascertain the average efficiency of the locomotives as a whole, working under the constantly varying conditions of speed, load, and electromotive force." He would ask the Author to supply a list of the brake tests of one of the motors used on the City and South London line, which would be exceedingly interesting. He feared that the efficiency was not very high, and he based that fear on the fact that the pole-pieces compared with the rest of the magnetic circuit were very thin, and the lines of force were not distributed

Mr. Reckenzaun.

Mr. Reckenzaun. all over the armature to give the maximum useful effect. He considered that a rather important point. The working expenses seemed remarkably moderate, and the sum for repairs and renewals was surprisingly low, especially wages and material. He hoped that there had been no mistakes made in the book-keeping. He had been a great traveller on the South London line, and in the early days the breakdowns were very frequent. Several of the armatures burned out in a week, sometimes one every day. Winding the armatures in those days was not a very easy or cheap matter. It appeared to him that the cost of repairs for the half-year ending December 31st, 1891, during which time they were, to his knowledge, frequent, was very low. Wages for six months were put down at £26 3*s.* 9*d.* and materials £193 13*s.*, a very low sum indeed considering the experience he had had.

Mr. Parker. Mr. T. Parker said that reference had been made in the Paper to the weight of the trains. In Liverpool the weight of the trains carrying 5-ton motors was 40 tons, when fully loaded with one hundred and fourteen passengers; while the weight of the trains described by the Author was 40 tons, and 10½ tons carrying one hundred passengers. Reference was also made in the Paper to the torque of the motor. The torque effort of a motor in starting a train was a most important factor, economy and efficiency being in a great measure secondary points. The Author stated that he had a torque effort of 1,180 lbs. with 100 amperes. In Liverpool they had a torque effort of 1,450 lbs. with 100 amperes, and that upon a diameter of 2 feet 9 inches, the wheels on the South London line being 2 feet 3 inches. With 120 amperes at Liverpool they had 1,800 lbs. torque effort. He hoped some day to be able to set those matters forth more fully. He should be glad to see some more detailed statement in regard to the motors, as asked for by Mr. Reckenzaun. With regard to the compound dynamos, working under the conditions mentioned, he thought they must be very difficult to handle, and that the conditions were not likely to give them a very long life. He should be glad to see some of the characteristic curves, and some statements of all the conditions under which they worked. They could judge but little of the motors or dynamos from the information given. He could only account for the difference by Mr. Reckenzaun's suggestion that the magnetic system was not as good as it might be. Neither did the locomotive as arranged allow of the advantages obtained under the carriages as used in Liverpool. In Liverpool they used two motors, one with each carriage, making two carriages a train, the motor being part of

the carriage. The difficulty of handling an independent locomotive was therefore done away with. It was not necessary to reverse the train at Liverpool, it was ready to start back immediately it arrived at its destination. They also did with two men on board the train, but it appeared that they required at least three in London. He imagined that they would be well able to deal with railway traffic without locomotives in most cases. Locomotives might be advisable under certain conditions. Where ordinary trains required to be drawn from the outside stations into the centre of London, locomotives would probably do that work with the present railway stock. He saw no difficulty in building locomotives powerful enough for that purpose as for any heavy work that might be required. He hoped to be able to show that they had made a great advance in the motors built for Liverpool. The Author had stated that he had a conductor 1 inch below the rails in the subway and wooden bridges to carry the slippers over at the crossings. He did not know what that could be done for. At Liverpool they had it 1 inch above the rails, and they needed no bridges of that kind. The slippers were continuous over the points wherever they went. The Gramme armature was used in the motors described by the Author. He thought that was the reason why the motors were not so good as they had been able to obtain in Liverpool. In further practice it would, he thought, be found that the Gramme armature was not the armature for that kind of work. The means of supporting it from the axle were mechanically bad, considering the various strains and the hammering to which the mass of the armature must continually be subjected. Although after two years no trouble had been found, still the construction of the motors would be a very important point in respect of the life, maintenance, and cost of the railway. At Liverpool they had adopted a system of insulators which were very efficient. He should like to see diagrams showing the power required to accelerate the trains in the subway. The Author had said something about air-friction in the tunnel, but unless he stated how much it was the reference was of very little value. He had often seen the Author's arrangement of the jockey-pulley, but could never learn to love it. Whatever mathematical proof might be given to show that it was a good thing, as a mechanic he could not accept it unless to meet special conditions. Mr. Parker.

Mr. Gisbert Kapp said it would have been a great advantage to the Institution if the Author, in his otherwise admirable Paper, had given some particulars as to the history of the failures or Mr. Kapp.

Mr. Kapp. slight mishaps which undoubtedly had occurred on the line. In asking for such information he had no wish to draw attention to the fact that there had been such failures, because, in a pioneer undertaking of such magnitude where almost everything was new, it could not be expected that the different parts of the machinery and other works would be perfect from the first moment. It would have been, however, in accordance with the traditions of the Institution if the slight failures or break-downs had been mentioned, and also the means by which the difficulties were overcome. The Author had referred to the advantage of putting the armature direct on the axle of the locomotive. There could not be two opinions as to that. The question was whether there was or was not some greater tendency to break down due to mechanical shaking. The Author seemed to think that there was not. He would ask whether, in addition to mechanical vibration, there was any other reason why the armatures should have broken down more or less frequently? They did not break down at present, so that he presumed the fault had been removed. The employment of compound-wound generators was, he believed, a new departure in generating machinery for electric railways. As a rule the machines were separately excited, or shunt-excited, and he was doubtful whether compounding was a happy departure. The idea of using a compound machine was that it should adapt itself to the increase of load by raising the voltage at the generating station and so making up for the loss of voltage on the feeder. If they had to do with a small machine of 20 or 30 HP. that object would be undoubtedly attained, but they had to do with a machine of 200 HP., the field magnets of which were very heavy and massive, and such machines took a considerable time to alter their magnetic condition. There was a kind of magnetic inertia in the field magnets preventing the machines from responding readily to the change of load which happened in electric railways with alarming rapidity. It would be noticed that the period between the maximum and minimum load was a matter not of minutes, but of seconds. A machine of that massive build could not alter its magnetic condition in a short time. The result was that compounding did not fulfil all the expectations of the designer. The machines were admirable for steady loads or for loads which changed slowly; but he did not believe that with rapid changes of load they kept the voltage at the feeding points on the line even approximately constant. There was another objection to the employment of compound machines for that sort of work. The machines were not

coupled at the station, but they were coupled in a measure by the line, and it was quite possible that two compound machines coupled in parallel would come to grief by one machine sending currents through the other in a wrong direction, reversing its field. He should be glad if the Author would state whether any means were adopted to prevent such a catastrophe, for it would be nothing short of that, or whether he had never arrived at the verge of that dangerous condition. One suggestion made in the Paper, which he believed was originally brought forward by Mr. Reckenzaun, was that the very rapid variation of load should be met, to some extent at least, by the employment of secondary batteries. The secondary battery would be put in parallel with the generating machine, and would act as a kind of electrical buffer, giving out power when the machinery was heavily loaded and taking in power when there was some to spare, because the line did not take the full current. Having inquired into the question whether that could be done by secondary batteries, he obtained this result. If it were desired to use batteries and work them up to their full discharge capacity, they would in that case have to be content with obtaining only 400 volts when the load was high, and would have to apply about 500 volts when the load was light; that was, the voltage, instead of varying 60 volts as at present, would vary 100 volts, in order that the batteries might take and give power. In this way the present excess load could be diminished by about one-half if two batteries were employed, one in the City and the other at the Oval station. Each of those batteries would cost about £3,000; and their depreciation could not possibly be placed lower than 10 per cent. per annum, because they would be worked under very trying conditions. This was a very high price to pay for taking off part of the strain. There was also the disadvantage of a great variation of the voltage, because a battery when working at its full rate required for the charge 2½ volts per cell, while it only gave 2 on the discharge. It was, of course, possible to work batteries between narrower limits of voltage; but then they must use cells which were far larger than was absolutely necessary, and the cost would become proportionately higher. The question was, could this very important object of diminishing strain, which really meant reducing the amount of steam-plant at work and coal burned at the generating station, be obtained in some other way? He thought it could. In this connection, he would like to mention a case which he had to deal with about fifteen months ago. It concerned electric power-transmission—600 HP. transmitted to

Mr. Kapp.

Mr. Kapp. a spinning-mill in Switzerland. The power was obtained from several motors, amongst which was one of 100 HP. nominal, driving a whole floor of self-actors. The self-actors took a moderate amount of power taking the mean; but at the moment of the carriage returning they took a considerable amount of power; and if there were six or seven of those self-actors returning at the same moment, the strain on the motor became very severe. The power was estimated from the indications of electrical instruments, which, owing to the sudden changes of load, were difficult to read, but, as nearly as he could ascertain, the mean power was 96 HP. and the maximum 150 HP. The motor would work for three or four minutes fairly steady, then on a sudden it would give a few fluctuations. The period of fluctuation was fifteen seconds, namely, the time between the forward and backward return of the carriages. This was cured by the simple application of a fly-wheel weighing 1 ton put on the motor spindle. The speed of the motor was 600 revolutions. In designing the fly-wheel, he allowed for an average variation of 5 per cent. There must, of course, be a speed-variation, so that the fly-wheel might act. That got over the difficulty completely. He thought it would show what might be done on electric railways if they were to put on in one or two parts of the line a shunt-wound dynamo with a magnet excited in a particular way, and driving a fly-wheel, but doing no other work. If the fly-wheel rim were 6 feet in mean diameter, and weighed 2 tons, then with a variation of speed from 700 to 500 revolutions, they could store in such a fly-wheel 45 HP. output from the dynamo for one minute, or in electrical measure 2,000,000 joules. This would be amply sufficient for starting three trains at once, bearing in mind that the generating station also supplied power all the time. It would in that way be possible to get over the difficulty of having heavy strains on the generating machinery, and owing to the more even flow of current, the feeders would work at a higher efficiency. The fly-wheel dynamos in themselves would waste very little power and would require no attention. They would simply run all day as long as the current was on the line. They would take power and speed up when the load on the line was light and give out power and lose speed when the heavy strain came on; and as the period of strain only extended over ten, twenty, or twenty-five seconds, a comparatively small fly-wheel would give out in that short time a large amount of power.

Mr. Greathead. Mr. J. H. GREATHEAD said he was not sure whether he ought not to apologise for not having before presented a Paper to the Institution descriptive of the City and South London Railway. He

regretted that it had not been done, because if it had been a great part of the Paper might have been left unwritten, and the Author might have added some other facts in reference to his particular part of the work, such as those to which Mr. Kapp had referred. He hoped to be able to prepare a Paper on the subject during the present session, and that it would be published in the same volume as that which contained the present memoir. He hoped that he should not be considered hypercritical if he began with the first words of the Paper, namely, the title, which seemed to him to be a mistaken one. He thought it ought to have been "Electrical Traction," or "Electrical Traction on the South London Railway," or "Electrical Traction on Railways and Tramways," not "Electrical Railways." It was to all intents and purposes a Paper upon electrical traction, and not upon the railways themselves. Referring to the historical part of the Paper, he might be permitted to refer to the statement in reference to the consulting engineer. The Author had said that Sir John Fowler and Sir Benjamin Baker were the consulting engineers at the commencement of the undertaking, whereas, as a matter of fact, Sir John Fowler became consulting engineer two years afterwards, when the company was launched. He thought that some tribute was due to Mr. Mott, the Chairman of the South London Company, for his action in reference to the question of electrical traction. It was due to him that electrical traction was employed upon the line. He first of all took great pains to satisfy himself, and then his co-directors, and finally his shareholders, that electrical traction had made such advances that it offered attractions superior to those of the cable system, upon the satisfactory working of which Parliament had granted the powers for making the railway. Among the enquiries which were made were invitations to a number of firms in England and America to send in proposals to the Company for working the line by electricity. The first proposals were of a general character, and were so divergent that it was almost impossible to compare them. Accordingly, tenders upon a specification were invited from the same firms, and the result was that the Company received from about half-a-dozen firms in England and from one in America proposals for constructing electrical plant, and working it in some cases. He thought it right to make that statement as showing that at that time there were in England a number of firms who were prepared to undertake that very important work, novel as it was, without at all wishing to detract in any way from the skill and enterprise of Messrs. Mather and Platt, who had carried out the work. Very important

Mr. Greathead.

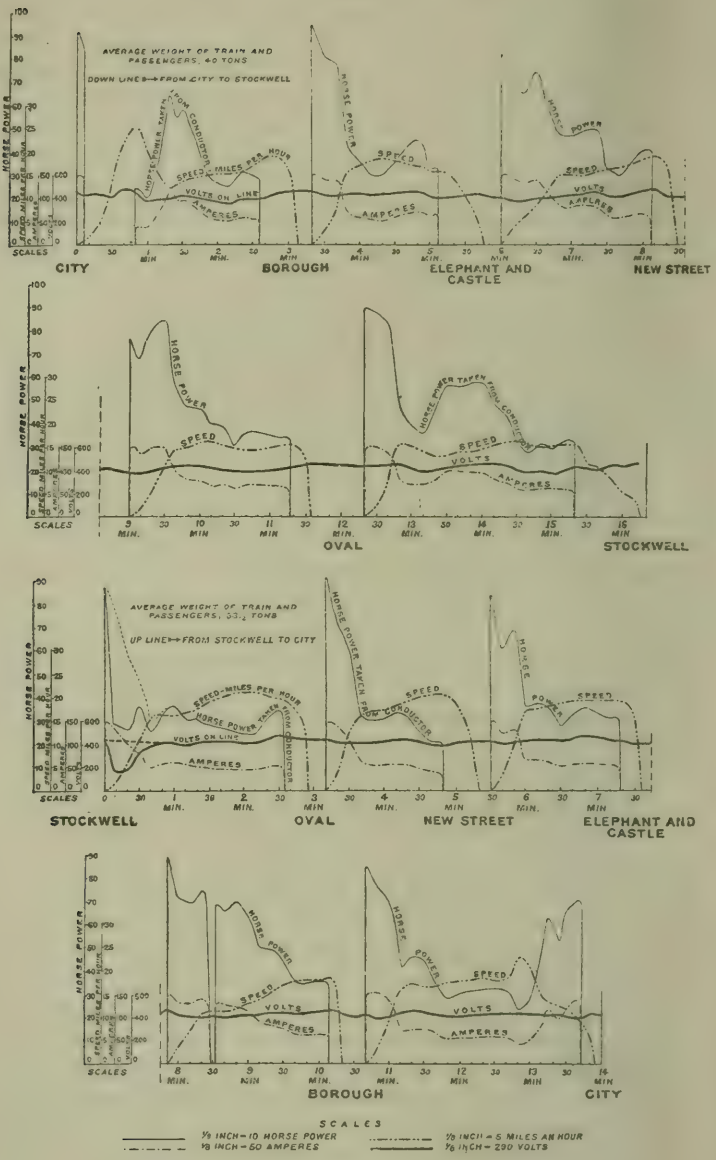
Mr. Greathead. modifications were made in the proposals of Messrs. Mather and Platt, and one of the conditions was that they should, within a very short period, run one of their locomotives upon the line with two of the actual carriages that were to be run upon it finally. Experiments were made upon the line with those carriages for about nine months before it was opened, and consequently they had a full opportunity of estimating exactly what had to be done. He made that statement because it might be inferred from some of the remarks in the Paper that Messrs. Mather and Platt had been left in ignorance of what they had actually to do. He might add that the experiments were made upon the most difficult section of the line, viz., the City section where the gradients were steep and the curves sharp. He proposed to confine his remarks exclusively to matters connected with the traction, some of which he thought were of importance. It was stated in the Paper that there was no duplication of the steam-pipes. That was the case when Messrs. Mather and Platt had to do with the line, but since then a duplication of the steam-pipes had been introduced, and the works were perfectly safe in that respect. The chief reason for not employing condensing-engines was the difficulty of disposing of the hot water, which it was not allowed to discharge into the sewers. The Author had suggested that in the larger tunnels that were now contemplated in connection with electrical railway schemes there would be an opportunity of placing the conductors overhead instead of between the rails as had been hitherto done, both on the South London line and on the Liverpool Overhead Railway. He might observe that that was not his intention in proposing those larger tunnels. The intention was to give the power of putting in larger and more roomy carriages, and a better system of permanent way. He saw no reason why the conductors should be placed overhead. Dr. Hopkinson had stated that the system used on the South London line had worked well, and he did not see why it should not work equally well on all other lines. The Author had discussed the question of geared as against direct-action motors. One of the great arguments against direct-action motors to which the Author had not referred was that, on account of its larger size, it took, at the present time at least, a much greater current at the start. That meant a very great and sudden load upon the dynamos and engines, and it was an important matter, not so much on account of the actual loss of power as on account of the effect at the generating-station. The effect was that the generating plant must be very much more powerful than would otherwise be necessary.

Mr. Greathead.

Figs. 3 would illustrate that, showing, among other things, the horse-power taken by the locomotives from the conductors in taking a train from the City to Stockwell and back again. It would be seen from those diagrams how very large the current was, and the corresponding horse-power at the commencement of each run. The greater part of the large spikes represented loss. That loss was not peculiar to electrical working; in cable working very much the same thing occurred. When the grip was applied to the cable before the carriage or train reached the velocity of the cable, the cable itself must have travelled twice as far as the carriage, consequently the loss in power was equal to that necessary to overcome the inertia of the train. That was a considerable loss, although in that case it had not the same serious effect upon the engines in the generating station, because there was the inertia of the cable assisting the engines. Starting with the diagrams in *Figs. 3*, he had constructed two others, *Figs. 4* and *5*, one for a service of nine trains with intervals of four minutes, and the other for a service of seven trains with intervals of five minutes between the trains. It would be seen that the variations in power were very considerable. The shaded spikes which he had added indicated the power taken by the turnover locomotives at the terminal stations. That was interesting as showing the effect of the starting even of a locomotive of only 10 tons upon the machinery at the generating station. *Fig. 6* showed the actual effective power that he estimated to be required for the line when electricity was first talked of. They showed the power required on the rails for a service of ten 30-ton trains with three minutes intervals, and it corresponded very closely with the others when account was taken of the difference in speed and in the weight of the trains. The great objection to a geared locomotive, at any rate in connection with tunnel-railways, was the intolerable noise it made. The Author had said that a geared locomotive was constructed for the South London Railway. That locomotive was very seldom used, the principal reason being that it made such a noise that it could be heard three-quarters of a mile away, from one station to another. Directly it started the hum of it was distinctly heard. Another objection to a geared locomotive was the difficulty of hauling it. When it got out of order it had to be hauled, and it was more difficult to haul a geared locomotive than a direct-acting one. The Author had given four reasons in favour of gearing. He did not think that there was any force in the first in regard to separate locomotives, because it was found already that separate

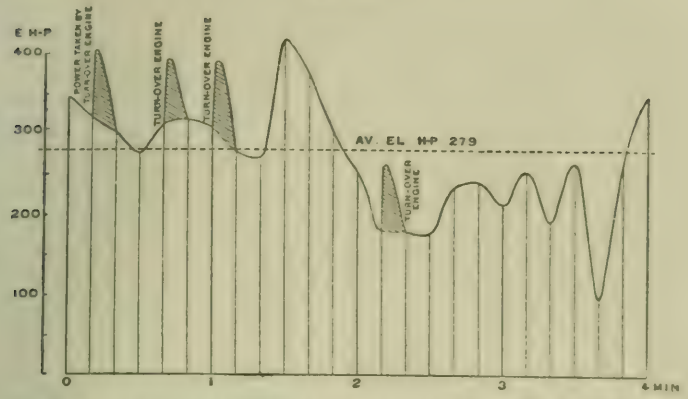
Mr. Greathead.

Figs. 3.



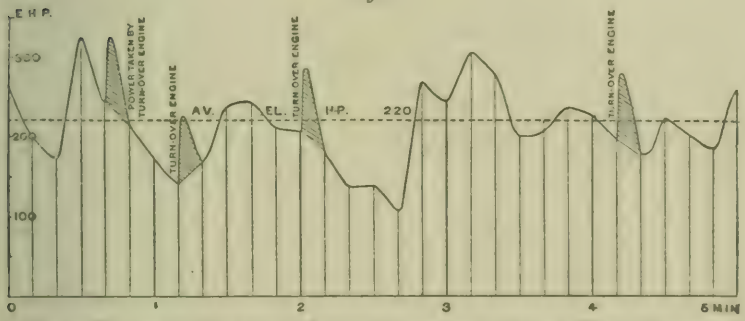
Mr. Greathead.

Fig. 4.



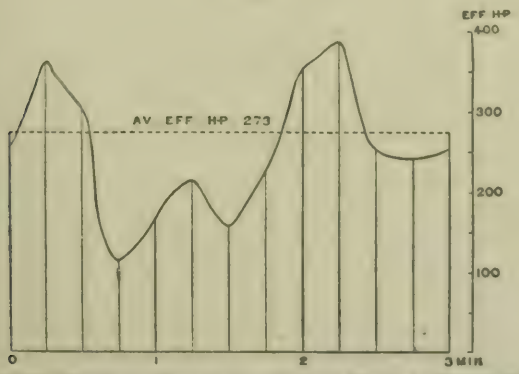
NINE TRAINS RUNNING. INTERVAL BETWEEN TRAINS, FOUR MINUTES.

Fig. 5.



SEVEN TRAINS IN RUNNING. INTERVAL BETWEEN TRAINS, FIVE MINUTES.

Fig. 6.



TEN TRAINS RUNNING. INTERVAL BETWEEN TRAINS, THREE MINUTES.

Mr. Greathead. locomotives had not the adhesion corresponding to their power; on steep gradients the wheels would skid, showing that the power of the locomotive was greater than its adhesion, consequently there would be no object in reducing the weight of the motors. Of course in a separate locomotive there was plenty of space for the motors. Number two did not apply, because, as the Author had shown, the vibration had no bad effect upon the motors. The other two points were at least doubtful. The Author had given the torque of the motor at 100 amperes and 226 amperes. He did not know what the effect of 226 amperes would be upon the motors; but he did know that 150 amperes, which was the current always used in starting the trains, had been the cause of some trouble. At first a great deal of trouble and loss had been occasioned the company through the damage to the armatures, resulting, he believed, entirely from the rush of current through the motors at the start. The remedy was found by Mr. Basil Mott, the resident engineer on the line, who wound a number of the armatures with square wire instead of round, and there had been no trouble since with those armatures. For many months the locomotives had been running without giving any trouble at all; but it was only by the exercise of the greatest vigilance and care that that end could be obtained where the armatures were constructed with an insufficient section of wire. The next point was as to the brakes. He had been asked "Why do you not use electric brakes in connection with your trains?" To begin with, when they started the work, there had been no electric brakes tried in which they could place confidence; and, in the next place (which was the most important reason), he thought that it was very much safer not to depend upon electric brakes upon an electric railway, where, possibly through the failure of the current, they might want to put on powerful brakes exactly at the time when the current failed; consequently, they adopted the Westinghouse brake with a reservoir upon the locomotives. That had been found to answer so well on the South London Railway that they had adopted it on the Liverpool Overhead Railway. In reference to one passage in the Paper, he thought it was only fair to Messrs. Siemens to state that their locomotives, which were supplied subsequently to those of Messrs. Mather and Platt, were upon a design which they had themselves submitted with their proposals sent in to the company, and that they were not copied from those of Messrs. Mather and Platt. The Author had made some remarks on air-resistance on railways of that kind. He (Mr. Greathead) did not think that air-resistance was a very

important element. He went into the subject very carefully, and he regarded it thus—taking the area of the train as equal to half the area of the tunnel, and, assuming as an extreme that the ends of the tunnel were completely blocked up, the locomotive, in passing towards the blocked end, would have against it the air which would have to pass at the same velocity in the opposite direction; and, consequently, in those conditions there would be an air-resistance equal to that due to twice the velocity of the train. That, of course, would be four times the resistance that there would be from still air in the open. But the ends of the tunnel were open, and there were connecting passages between the up and down tunnels, and on an average it might safely be assumed that the air-resistance would not be more than double that of still air in the open. He had taken the trouble to calculate from the current taken by the locomotive what would be the average resistance on the line, and he found that from one end to the other, taking the average current, the average resistance would be 13 lbs. per ton for those small trains, and that the maximum resistance would be 20 lbs. at twenty-one miles per hour, which corresponded very closely indeed with the amount he had estimated originally, which was from 13 to 21 lbs. With reference to the question of separate locomotives as against motor-carriages, no doubt where motor-carriages could be used, as on the Liverpool Overhead Railway, where there was plenty of head room and they could be put on the bogies under the carriages, and where the trains were short, motor-carriages were the right thing. There could be no question about that because the weight hauled was reduced, and the terminal shunting was avoided. He had shown on the diagram the effect of terminal shunting at the generating station. In addition to that it was always necessary to keep two locomotives with their drivers and assistant drivers, who were half their time not running. Then a very important matter was the first cost. He had looked into the figures and had found that on the South London Railway the cost for about the same seating capacity was about £1,000 per train more than on the Overhead Railway; and the chief difference was on account of the separate locomotive. Of course, on the South London line, there was no room under the carriages; the curves were too sharp to admit of the carriages being lengthened, and therefore it became a question of multiplication of vehicles in any case, and it was decided, and he was sure quite rightly, that the locomotive should be separate and not a part of the carriage.

Mr. Greathe

Sir Frederick Bramwell, Past President, said he had only one

Sir Frederick Bramwell.

Sir Frederick Bramwell. observation to make. Mr. Greathead had remarked that the main reason for not having condensing engines was the difficulty of getting rid of the hot water, which was not allowed to go into the sewers. He desired once more to repeat, that which he had so often said at the Institution and elsewhere, that they could in every instance, where there was a sufficient supply of water to feed a non-condensing engine, have condensation with the respectable vacuum of 26 inches without sending any water away at all, by the use of the evaporative condenser delivering simply a "reek of steam" into the air; and further, from what he had seen at Stockwell, he should say there was ample room there to have an ordinary injection-water pond. At all events, he thought that no mechanical engineer would be at all troubled to apply condensation to those engines on the ground that he could not send hot water through the sewers. He might mention that on the Surrey side of the river, and just to the west of Charing Cross Bridge there were two engines which had been working, one for twenty years and the other for thirty years, where the vacuum was made entirely by evaporative condensers such as he had mentioned.

Mr. Greathead. Mr. GREATHEAD said that they had not abandoned the idea of using condensing engines, and they hoped that they might be able to send the hot water into the gravel.

Mr. Cowper. Mr. E. A. COWPER said that Sir Frederick Bramwell had taken the words out of his mouth. If they were short of water they ought to use the condensing engines, because they could do with less water than with high-pressure engines. That he most distinctly maintained. There was no question of sending the hot water down the sewers or elsewhere, because the water that was used with a surface evaporative-condenser disappeared, taking with it the latent heat, and thus keeping the temperature of the pipe low enough to produce a good vacuum, namely, 28½ inches inside the pipes, which were connected to the engine. The important practical point in favour of condensing-engines was this, that the steam did so much more duty in an engine with a good vacuum that only about 220,000 lbs. of water would be required to do the same work as 330,000 lbs. in a high-pressure engine, and only two-thirds as much coal would be necessary. A little hard water should be mixed with the soft, distilled water for feeding the boiler.

Dr. Hopkinson. Dr. JOHN HOPKINSON thought it only justice to Messrs. Mather and Platt to explain the slight discrepancy existing between the weight of the cars, as specified in the first instance, and the

weight which they were afterwards found to be. Mr. Greathead had said that Messrs. Mather and Platt should have found out that difference at the time at which they made their somewhat lengthened experiments when the railway was opened with their single pair of locomotives. The purpose of those experiments was threefold. First, they wanted to ascertain what kind of commutator and what kind of brush were the best. Secondly, they wanted to see whether the better plan was to use series-dynamos or shunt-dynamos; and thirdly, they wanted to compare the direct-action dynamo with the geared dynamo. Those three points they did pretty satisfactorily ascertain. They did not go into any considerable examination of the question whether the size of the wires of the dynamos was adequate. The runs upon that railway were hardly long enough to ascertain that point, and Messrs. Mather and Platt relied upon their general experience of what the wires were calculated to carry, and what would cause them to give way, rather than upon the experiments themselves. For his own part he never dreamt of the carriages weighing more than the weight specified, and he was sure that if Messrs. Mather and Platt had anticipated anything of the kind he should have heard of it. Fortunately in the result the difference did not cause much trouble. Undoubtedly at first a certain number of armatures gave way owing to the greater load to which they were exposed compared with that which they were designed to carry, but, as Mr. Greathead had stated, a very slight alteration was found to be sufficient to make the same motors do the increased work. Consequently, owing to the fact that there was a margin and that it was possible to increase the output of the motors to that slight extent, no serious trouble had resulted. Reference was made in the Paper to the existence of earth currents from the tunnel. Those currents could be detected so far away as Greenwich by the wires used there for the purpose of investigating earth currents. He believed at no time had they been so considerable as to cause serious disturbance either to the telephones or to the telegraphs; but of course from the telegraphs they could hear of their existence. They had been materially diminished by the expedient referred to in the Paper, viz., that of connecting successive sections of the tunnel by means of a conductor. That, however, did not completely obviate the inconvenience, no doubt from the fact that the segments of cast-iron, of which the tunnel was composed, were separated from each other in a greater or less degree by a comparatively non-conducting layer of oxide of iron. He believed that if the trouble were still found to be serious, it

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Mr. Hopkinson. could be almost completely prevented by annihilating any metallic connection between the rails and the shell of the tunnel. That would be some little trouble, but it would not be impossible. If it were done, they could interpose between the rails whereby the current returned and the shell of the tunnel, a considerable resistance, possibly of some hundreds of ohms. In that case the earth current would be diminished in something like the ratio of the actual resistance of the shell of the tunnel and the earth surrounding it to the interposed resistance between the shell of the tunnel and the rails. The next point to which he desired to refer was the method, which he believed he was the first to propose, of diminishing the great strain upon the locomotives in traction by means of a switch which should put two motors, if there were two, upon the car in series or in parallel at pleasure. He did not agree with the Author that the economy to be realised in that way would be insignificant. The actual power saved by the mere saving of that which was a loss would be material. But that was not all. Mr. Greathead had already referred to the fact that owing to those very great currents and strains at starting, it was necessary to provide a greater plant—heavier conductors, and that that plant had to work with a more variable current than would be the case if those heavy strains were diminished. For that reason it seemed to him that there would be a very material economy indeed resulting from an arrangement whereby the two motors could be put in series in starting and switched into parallel when the speed was got up. The addition would be slight. Instead of having a reversing switch, they would require a switch for putting them in series and parallel, and possibly two switches for reversing. On the other hand, they would be able to diminish the resistance upon the car which was needed to take up the excess of pressure at the moment of starting. Reference had been made to the question whether the conductor should be placed overhead in the tunnel or between the rails. The Parliamentary Committee last year recommended that the conductor should be placed overhead, on the ground that it was safer for the public. As far as his own experience went, on the City and South London Railway, there was no danger to the public; he had never heard of any member of the public receiving so much as a shock from that system. Probably one would have heard of it if they had received a shock, for those shocks, though not very severe, were disagreeable. He had received shocks on the railway from the 400 volts, and though they were disagreeable, they were by no means dangerous.

The public had two lines of protection; first they had the certainty that they would not get any shock at all, and, secondly, that if they did get a shock it would not hurt them; but he agreed with the Author that there were other reasons which would induce them to place the conductor, if the conditions were favourable, overhead. One of those was the greater simplicity of arranging points and crossings. If points and crossings were at all complicated they would find a difficulty in placing the conductor between a pair of rails; if they were overhead they had nothing to deal with except the conductors themselves, and that was comparatively a simple matter. For that reason he should strongly advocate, where he could do as he pleased, the placing of the conductors over the cars in the tunnels. He did not know whether the discussion was to be strictly limited to the question of railways, or whether he could be permitted to refer to the question of tramways. With regard to the working of tramways by electricity in America, they had carried their experience very much further than in England, at all events they had carried their schemes on an enormously greater scale. But he thought that English engineers had yet to learn that it was their duty to copy precisely what was done either in America or anywhere else. They had their own conditions to meet, and they were willing to learn what they could from all the world, but they had to consider how it would apply to the conditions in this country, and to adopt what appeared to them to be the best. What was the reason why electrical tramways in England had made such comparatively slow progress? Partly, no doubt, it was the objection which the public felt to the idea of having multitudes of conductors strung over their heads through streets, interfering with fire-escapes and creating annoyances, which, if not very serious, certainly amounted to something. Whether they liked it or not, the British public would object very seriously to carrying the conductors of tramways overhead, and if they were not to be carried in that way, they would have to be carried in some other way, or accumulators would have to be used. Accumulators had been tried very extensively for tramway purposes, but, as far as he knew, they had never been a commercial success. Fortunately there was another method, viz., that of conductors made in a trench underground and communicating with the car by a slot. He believed that plan was first introduced at Blackpool, but it was now in use on a much larger scale at Buda Pesth, where the work had been carried out by Messrs. Siemens and Halske, of Berlin. They had there a tramway of about 11

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Dr. Hopkinson. kilometres (7 miles) in length; it was a double line, therefore being about 22 kilometres, and they had running upon it about sixty-three cars, all of which were sometimes at work. They carried a very considerable number of passengers, and made a profit. They charged a low rate, and the cost was something like 4*d.* per car-mile, including all charges, taxes, and everything. They were extending the line upon the same system. What were the objections to that system in this country? Surely, only two. First, there was a certain objection to the existence of the slot in the road. The slot at Buda Pesth was about $1\frac{3}{8}$ inch wide, and he believed that no objection had been taken to that width. He did not, however, think that such a width was at all necessary. He should not hesitate to undertake to arrange an electric tramway with a slot not exceeding 1 inch in width, with the exception perhaps of a fractional increase at the points, and such like. The other objection was the cost. The cost of a culvert would be probably somewhat over £1,500 per mile in excess of the cost of an overhead conductor. If the pavement were costly, it would be something more, making an additional cost perhaps of £2,000 per mile. In this country, corporations could borrow money at less than $3\frac{1}{2}$ per cent., so that the additional cost, exclusive of maintenance, if there were any—he did not believe there would be, having regard to the possibility of breakdowns by snow, and so on, with overhead conductors—the additional cost of using the culvert system would be confined to about £70 per mile per annum. That was not a very large matter. In populous districts where cars were frequent, he had no doubt that the general public would be content in one form or another, whether out of the rates or out of the fares, to pay that amount rather than have the annoyance of overhead conductors. His view was that if one had to put up a tramway in any of the large towns, the proper system to adopt would be that of the culvert, with a narrow slot, as narrow as convenient—certainly not more than 1 inch—to connect the car with the conductor.

Mr. Preece. Mr. W. H. Preece said he wished to supply one omission in the Paper, which had been slightly referred to by Dr. John Hopkinson, viz., the disturbance that had been occasioned by the South London Railway upon the telegraphs and telephones of London. The line was opened in November 1890, and immediately it commenced to work there was scarcely one telegraph circuit in the South of London that was not violently disturbed. Every single line was subjected to a fluctuating current of a peculiarly distressing and errant character. Not

Mr. Preece.

only did this extend as far as Greenwich, where it was observed upon the delicate instruments of the Observatory, but it extended as far as North Walsham in Norfolk, a station not very far from Norwich. North Walsham happened to be a very important station for telegraphic purposes to the Continent; it was the point were the most important German cables end, and where the connection between the submarine portion and the land line was made. Here the currents were observed, and the clerks in charge of the apparatus were able to distinguish the motion of every single train upon the South London Railway. It was a most remarkable fact that the disturbance produced by that railway on the currents working the railway in the earth in London should extend to such enormous distances, and he had not the least doubt that if instruments sufficiently delicate were installed, they would find the same currents evident in Manchester, Liverpool, and perhaps even Glasgow. However, in North Walsham this was studied, and in order to get records that would give some idea of what they were, he had established at Tottenham, on the North Walsham line, instruments that enabled him to record curves which he had the pleasure of sending to Mr. Greathead and Mr. Mott, as an indication of the watchfulness maintained on the correct traffic returns of that railway. Although these currents had been observed, he did not think any one had seen a case in the Law Courts of any action brought by the Postmaster-General against the South London Railway. It fortunately happened that the responsible officer of the Postmaster-General was deeply interested as an electrician himself in the progress of the application of electricity to the working of railways. He took every possible opportunity to bring these facts to the notice of the responsible officers, and he was bound to say those responsible officers of the railway did all in their power to reduce these disturbances. The effect was diminished, and although they could still see the motion of every train in the General Post Office in London, it did not disturb the telegraphs, and they did not care about it. It would also disturb the telephones, if, fortunately for the railway company, those telephones were not shielded by an iron tube. It did not affect the telephones of the Telephone Company; if it did, no doubt the law would have been brought to bear before this. The principal reason of the non-interference was that the South London Railway adopted the gearless motors, and not motors either with single or with double-reduction gear. Where reduction gear was at work there were pulsations due to the passage of the brushes over

Mr. Preece. the commutators of very high frequency indeed, and the result was a very distressing sound. If any one had been down to Leeds and listened to the sound of the disturbance produced by the Leeds tramway in starting, they might be strongly tempted to throw away the telephones pretty quickly. It was not so in South London, because the number of pulsations produced by the gearless motor were so few that the sound produced a very low and deep note and one which did not annoy the ear. The cause of these disturbances was bad insulation. The Author said, "The return circuit is through the rails, which are practically uninsulated. In such a system high insulation from the earth is neither aimed at nor required, provided the power lost in leakage is inconsiderable." He (Mr. Preece) contended that was not true engineering. Insulation was necessary, and if it was not maintained the power of the law would certainly one of these days be evoked against those gentlemen who were breaking the law. He did not think that such proceedings would be taken against a tramway company, but he was strongly tempted to believe that the electric light companies, who were using very powerful currents, increasing in magnitude, and whose disturbance to the telephones and telegraphs of the country were increasing every day, if they did not look to their insulation, would hear something very unpleasant one of these days, either from the legal authorities of the Telephone Company or the legal authorities of the Post Office. No reference had been made in the Paper or the discussion to the growth of this industry, not only in its application to railway purposes, but to the dimensions of the works of railways. At first it was a mere tramway, now the City and South London line had become a railway. The Overhead Railway at Liverpool was on a still larger scale, and he hoped soon to hear of Great Northern coaches being carried from Finsbury to the City in trains weighing 180 tons by locomotives, up a gradient of 1 in 30, with an expenditure of from 400 to 500 HP. The Americans had gone far ahead of the English in this direction. On the Baltimore and Ohio Railway they were going to use locomotives weighing 80 tons, which were competent to draw freight trains of 1,200 tons up an incline of 1 in $12\frac{1}{2}$, and exerting a HP. equivalent to 1,600.

Mr. Siemens. Mr. Alexander Siemens said that the locomotives at Baltimore referred to by Mr. Preece were not yet in existence. The Americans had merely invited tenders.

Mr. Preece. Mr. Preece said that his information had been derived direct from the firm that had the order, and was now executing it.

Mr. A. Siemens said that Mr. Greathead had referred to the design of the locomotive supplied to the City and South London Railway Company when the invitation to tender was sent out. But the Author was perfectly right in saying that there was a very great general resemblance between the two. That was because the company particularly requested that the arrangement of the switches should be exactly the same as those of Messrs. Mather and Platt, the reason being that the drivers, when transferred from one locomotive to the other, might know what handles to move in stopping and reversing. But the essential parts of the locomotive were really different. That would be evident when he stated that the resistance of Messrs. Mather and Platt's armature was 0·3 ohm; that of Messrs. Siemens was 0·18. The resistance of the field magnets of Messrs. Mather and Platt was 0·087; and the resistance on each of the bobbins of Messrs. Siemens was 0·96; but they were all four in parallel, so that for the current the resistance was 0·24. The reduction in the resistance of the armatures had the great advantage that the heat developed in the armatures was much less in Messrs. Siemens' locomotives than in the first ones, and consequently the consumption of the current was very much reduced, although the actual size of the motors was very much greater than that of the first fourteen. Mr. Siemens.

Mr. Llewellyn Atkinson said that the Author had expressed an opinion as to the use of high-speed engines in connection with the work, where the load was as variable as it was in the present case, to the effect that the lower-speed engines were more likely to give satisfactory results in point of wear. As he happened to have some experience of the Willans engines driving machinery working underground traction, hauling machinery where the load of course was as variable as in the case described, he might be permitted to give the results of the wear of the engines. It was true that the engines were not coupled in the same way that dynamos were coupled, directly to the engines. That had not been done for quite a different reason, a reason which he thought might have been considered in regard to the railways concerned. With reference to the output of the dynamos, it was stated in the Paper that they were each capable of giving 450 amperes. He presumed that each was capable of working a dynamo to 450 amperes. None of the curves in the Paper and on the wall, as far as he could see, showed any load exceeding 450 amperes. It would, therefore, appear that one dynamo in the station would be sufficient to supply the maximum current used. There were, however, in the station no Mr. Atkinson.

Mr. Atkinson. fewer than four complete sets of machinery, and he understood from the Paper that the fourth was supplied at the instance of the Board of Trade, who thought that there was not enough spare plant. His adaptation of the Willans engine for driving traction-work had been partly with the view of diminishing the amount of spare plant necessary. In the arrangement shown, if one dynamo or one engine broke down, the complete plant was at a standstill. By having two Willans engines, and placing them facing one another with a shaft between them, geared in a couple of independent bearings, and providing clutches at each end, not necessarily friction-clutches, two dynamos might be put down in a similar way, and then the engines and dynamos were working in pairs, and if one dynamo broke down, the other could be used with either of the two engines. The engines might also be thrown in and out; although the clutches were only pin clutches, it was possible to throw the engines in and out without stopping them. They ran them up steadily. They could drop the clutches in without the slightest check, and change from one engine to the other without stopping the dynamos or the plant. That was the reason why he used Willans engines for driving underground shafts not direct-coupled. By that means they could greatly save the haulage plant, and decrease the capital expenditure in duplicates. The engines had been running with that class of plant for more than two years, and in some cases there had been absolutely not a penny spent in repairs on that high-speed engine driving with quite as variable a load as in the other case. He had been able to make some measurements, not as complete as he could wish, to give a general idea of the amount of power which was lost in using an extra shaft and belting, as compared with the figures given by Mr. Thompson in a Paper where he stated that a direct-coupled Willans engine dynamo would give an efficiency of 86 per cent. between the indicator diagram and the electrical output. He found that from 4 to 5 per cent. was the outside loss by using an extra shaft and the belts, over what would be the effect of absolutely direct coupling. They had to take into account that 5 per cent. extra loss. He did not think it would be a serious item, looking at the amount of fuel and so on, and it would probably be more than covered by a decrease in the capital expenditure and in water-consumption.

Mr. Smith. Mr. Holroyd Smith said he wished to congratulate the Author on the fact that he had been associated with those who were prepared to take the onus of the conditions imposed

upon the contract, and that they had so ably supported him through its experimental stages. Only those who had worked out an undertaking of that kind could fully appreciate what he had had to endure and achieve before he brought the work to a success. He desired also to congratulate Messrs. Mather and Platt on the fact that they had succeeded in getting such modifications made to the terms of the specification upon which the competitive designs and estimates were formed, to enable them the more easily to deal with the details of the work, and further that they had had the good fortune to have so skilled and able a man as the Author to carry out the undertaking. The Paper dealt with a very interesting subject and one which, if thoroughly threshed out in all its details, would not only require an entire evening for the discussion, but all the evenings at the disposal of the Institution during the Session. He feared that an outsider, guided by a paragraph on page 211, would suppose that the proposal to work the City and South London line by electricity originated with Messrs. Mather and Platt, and that they were the only firm in treaty with the Directors of the Company. He was sure that the Author would not wish to convey such an impression, but Mr. Greathead had to be thanked for his remarks which removed any doubt upon the subject. The title of the Paper covered a wide field, but the Author had wisely concentrated his attention upon the particular work in which he had himself been most actively employed. Mr. Holroyd Smith would also confine his remarks mainly to the City and South London Railway, although, as Dr. John Hopkinson had introduced some questions relative to tramway work, he might be excused for making brief reference to that subject. In all engineering, the first principles must, of course, be sound, but successful work usually consisted of a host of details carefully thought out and executed. The Author, however, had favoured them with very few such details. Referring to the relative progress made in America and England, he wished to endorse all that Mr. Reckenzaun had said, which, no doubt, was the result of his own personal experience and observation and long intimacy with electric traction. On the subject of jockey-pulleys he wished to express some doubt as to the soundness of the Author's conclusions. The direction of a mass moving in one direction could not be changed without the employment of force. Further, if it took power to bend a belt one way it took power to bend it the opposite way—$\theta \pi \mu$ notwithstanding. He left that question to be dealt with by the mathematicians of the Institution. The explanation of harmonics was very

Mr. Smith.

Mr. Smith. pretty, but he doubted very much whether the continuance of the harmony, which he admitted was perfectly possible upon particular occasions, could be relied upon throughout the whole of the conditions that would occur in the employment of a jockey-pulley under such varying loads. As mechanics they could scarcely rely upon the poetry of motion. With regard to the generating dynamos, the Author wound his dynamos as compound ones. Mr. Holroyd Smith would not say that the Author was wrong in so doing, but he emphatically asserted that he should not venture to do it himself. He had laid it down as an axiom for his own guidance, that generators for traction-work should be separately excited. He had found in the Paper itself an element of doubt upon that very point, for the Author had stated—"The field-magnet coils are wound on both shunt- and series-coils, but the latter can be half short-circuited, or entirely so, at will." With reference to switch-boards the Author had said that automatic cut-outs were employed, but he had not given any details as to their construction. Knowing what those automatic cut-outs were, Mr. Holroyd Smith ventured to predict that they could not be relied upon for efficiency. They were constructed on the principle of being actuated by culminating weight. As soon as the current exceeded a certain amount it released the catch, the catch released the weight, the weight began to fall, and swung round, and when it had attained a velocity it struck a pin, and the pin knocked off the electrical connection. He had taken some little time to describe it, but not much more than it took the weight to think about it when it had the work to do. It was obvious that when dealing with a current of that magnitude when there was a short circuit, the break, or the interposition of resistances, must be made immediately. With regard to the question of conductors, he had no doubt others would feel obliged if the Author would give them the benefit of his experience as to some simple rules for easily dealing with a problem of that kind. Those who had to do with the distribution of electrical energy knew that the question of mains was no light matter. They required to be carefully considered and calculated, and a host of figures had to be gone through. The Author would be doing a service to electricians, especially those who had to deal with such matters, if he would state some simple method, at which he had no doubt arrived, of approaching that somewhat complex problem. The Author said that in distributing the electric energy over the line, automatic cut-outs were used to separate the main supply from any particular section of the line

where short circuits might occur. He was very much interested to find that that was so, and he ventured to think that it might be further extended and made more complete by an automatic system that would not only cut out a given section of the line when a short circuit occurred, but would also act as an automatic block system for trains. Mr. Smith.

He was pleased to find that the Author admitted that an overhead conductor would be preferable to the conductor upon the rails. He took exception to an expression that the Author had used—"but it was found impracticable on account of the exceedingly limited space available for such a conductor above the carriages." He wished to show that it could positively be done. The carriages were provided with longitudinal seats, and were entered from the ends; the roof therefore need not be of the railway type, but could be formed similar to those usually adopted in tram-cars, viz., hollowed along the side, and the space so obtained, instead of making room for roof-passengers' feet (as in tramcars), be utilized for the overhead-conductors fixed in the tunnel. The electricity could be gathered by a trolley or slipper connected to the locomotive by a metallic cord, which, being flexible, would allow the slipper to follow the conductor when outside the tunnel, where it would be sloped upwards to a higher level beyond the reach of passengers entering or leaving the carriages at the stations. These overhead conductors could be provided with points and crossings, and be worked by the levers that operated the rail points without detriment to the electric circuit. He had by experimental demonstration proved this to be possible. On the question of locomotives the Author, referring to the absence of the gear, had said, "Although the principle of direct drawing was suggested many years ago by Sir William Siemens, it has not previously been applied in practice." This statement would be more correct if the words "on so large a scale" were added. As to gearless locomotives the Author had based his conclusions apparently upon the fact that a certain occasionally-used locomotive fitted with gear had been tried, but he had failed to state what constituted that gear. They could form no opinion on the question whether a gearless or a geared locomotive was best on the statement in the Paper unless they knew what the gear was like. The Author had coupled Mr. Smith's name with that of Mr. Reckenzaun as having made certain experiments, and advocated the use of worm-gearing. He pleaded guilty to that charge, and he still advocated it; indeed, his experience

Mr. Smith. led him, the more he knew it, the more strongly to advocate it. If there was no gearing at all they must take advantage of a high ratio of difference between the motor and the axle to be driven. If it only went down to a single reduction 3 to 1, it was better to have direct driving. He might say that tests made by others of worm-gearing, for the design of which he was responsible, showed that with a load of 4 HP., at an axle-speed of 55 revolutions per minute, there was an efficiency of 72·25 per cent., and when the speed increased to 112 revolutions with 7·43 HP., the efficiency of the gearing alone was as high as 94 per cent. These results he knew would seem extraordinary to those who had not specially studied the subject, still they were obtainable. He certainly thought that gearing of any sort should be dispensed with wherever expedient, and had worked out a method of lessening the vibration of the armature when it drove the axle direct. Still the question of gear or no gear could not yet be considered as definitely settled, especially when dealing with tramcar work, in which he held that worm-gearing could be most advantageously employed. Respecting working motors in series, multiple and parallel, he had had satisfactory experience in so doing in the steep-hill-climbing demonstration he had recently conducted in Bradford, in conjunction with Messrs. Easton and Anderson. The practical difficulty lay in constructing a switch which would, with one continuous movement, change from one couple to another without interruption of current or temporary omission of one or more motors from the circuit. It was a totally different thing from dealing with variable resistances, and he should like to have known how the Author proposed accomplishing this. Dr. John Hopkinson in his remarks proposed designing a slotted conduit for street tramways with a slot 1 inch wide and employing insulated supply and return conductors; he would remind them that the first underground conduit he constructed contained separate insulated conductors positive and negative; in the various ones he had made, including that at Blackpool, no slot exceeded $\frac{5}{8}$ inch in width. Having regard to the important question raised by Mr. Preece, as to the effect upon telegraph- and telephone-wires of the strong currents from dynamos when the earth was used as a return, it occurred to him that a probable solution of the difficulty might be found in the combination of cable haulage and electricity for tramway traction, and he would suggest distributing the power from the generating station by insulated electric mains to drive electric motors, located at intervals throughout an extended tramway system, and employ-

ing these motors to actuate short lengths of cables running in slotted conduits for hauling the cars. Mr. Smith.

Captain R. Sankey (late R.E.) said that under the head of efficiency the Author had remarked that "probably no tests have been previously made on engines working under the abnormal conditions of a load constantly varying at very short intervals from one-fourth, or a less fraction, of the full load up to the maximum, and averaging a little more than one-half the maximum." He therefore thought it might be interesting to ascertain the consumption under somewhat similar conditions. The trial had been made with a G G size Willans compound central-valve engine capable of indicating 80 HP., and coupled direct to a Crompton dynamo, which happened to be under test at the time, and in order that the consumption at half-load should be in fair agreement with the figure stated by the Author (viz., 27·5 lbs. per indicated HP.), the cut-off was arranged so as to give the full load with about 100 lbs. gauge-pressure. The engine was governed by throttling. The load was altered by switching resistances in and out every half minute; the electrical load was observed, and the water consumption was measured by the well-known method devised by Mr. Willans, which enabled accurate results to be obtained in a very short time. The mean electrical HP. was found by calculation to be 25·6, and the total water-consumption was at the rate of 1,099 lbs. per hour. It was not, of course, possible to indicate the engine with such rapidly changing loads; but from previous trials the mean indicated HP. would be about 38·6, so that the water per indicated HP. would be 28·5 lbs. per hour. No consumption-trial had been made with this set for a steady load at 38·6 indicated HP.; but the consumption had been obtained at 76·4, and at 44·3 indicated HP., and by the application of the straight-line law, discovered by Mr. Willans, the consumption for a steady load of 38·6 indicated HP. was found to be 28·2, or sensibly the same as for the rapidly varying load as given above. The mean load of 38·6 indicated HP. was rather less than half the maximum load of the set under trial. In the case given by the Author, the mean load was 230 ÷ 400 of the maximum load, which corresponded with 46 indicated HP. in the trial set, and at this load the water per indicated HP. would be 26·7 lbs., or rather better than the figure mentioned by the Author. It should also be remembered that with the smaller engine the result was obtained with 110 lbs. boiler-pressure as against 140 lbs. with the larger engine. The Author had said that "it is doubtful, or at any rate remains to be proved, Capt. Sankey.

Capt. Sankey. whether a high-speed engine driving direct will give as relatively satisfactory results without undue wear and tear, and liability to accident when working under the abnormal conditions of load obtaining in traction work." Now, with regard to the engine itself it was difficult to see how loads suddenly and continually changing were likely to affect a high-speed engine more injuriously than a low-speed engine. The piston-speed was practically the same, and in either case the stresses produced in the moving parts, by changes of speed consequent on sudden changes of load, were but a mere fraction of the inertia stresses to which they were exposed at every revolution while working under a perfectly steady load; the advantage, however, being with the high-speed engine, in that the moving parts were very much lighter per HP. than those of the low-speed engine. Hence, if high-speed engines were as reliable as low-speed engines for steady loads, which they now had been abundantly proved to be, they would be at least equally reliable for suddenly and continuously changing loads. The effect of a short circuit on the dynamo would, however, affect a high-speed direct-driven set somewhat differently from a low-speed belt-driven set. When a short circuit took place, it was clear that it was not the engine, but the dynamo armature which was exposed to injury, the principal destructive power being the energy stored in the fly-wheel, the dimensions of which were of course determined, so that the fluctuations of speed should not be greater than some specified percentage of the normal speed. As an example, the fly-wheels of the three Willans engines, each indicating 200 HP., now being erected at Hobart, Tasmania, for an electric tramway, were arranged to weigh 1 ton each with a radius of gyration of 1 foot $9\frac{1}{2}$ inches. In a speed-trial with one of these sets (the engine being coupled to a Siemens dynamo), the energy stored in the fly-wheel at 350 revolutions was 140,000 foot-lbs. To get the same results, as regards evenness of speed, with a similar (Willans) engine indicating 375 HP. at 300 revolutions, it would be necessary to store 300,000 foot-lbs. in the fly-wheel. Turning now to the Stockwell engines, it was stated that the fly-wheel of each engine weighed 14 tons, and was 14 feet in diameter, so that the energy stored was about 2,400,000 foot-lbs., and it was believed that, in the last engine supplied, the weight had been increased to $15\frac{1}{4}$ tons, bringing the energy up to 2,600,000, or no less than nine times that required for the equal-powered Willans engine. One would suppose that with such a fly-wheel the fluctuations of speed would be less than those shown in Hobart tramway engines; but it had been stated

that such was not the case; it would therefore be interesting if the Author would give some figures, so that a comparison could be instituted. On more than one occasion the dynamos of Willans combination sets of 200 I.HP. had been short-circuited without any damage, and there was no reason to doubt that a Willans engine of 375 I.HP. could have its dynamo short-circuited with equal impunity. It seemed likely, however, that with a low-speed engine, in the fly-wheel of which it was necessary to store 2,400,000 foot-pounds, as against 300,000 foot-pounds only, the result would be very different. If it drove by belt, the belt would be likely to break. It was evidently better to have a direct-driven high-speed plant, subject to no such danger, than a low-speed plant, in which such danger could only be guarded against by means at once expensive and troublesome. Capt. Sankey

Mr. W. Shelford understood Dr. John Hopkinson to advocate the use of an underground conductor for electrical tramways in this country as against an overhead conductor, and to say that the additional cost would not be very great; also that he thought he could reduce the width of the slot which had been adopted on the electrical tramway at Buda-Pesth, from $1\frac{3}{8}$ inch to 1 inch. He need hardly say that the width of the slot was a very important point, especially in London. Those who had followed the development of street tramways during the last thirty years, knew well that for many years the great difficulty had been to devise a construction which would not make the wheels skid, or a groove in which the wheels would not catch, and so cause accident to life and limb, and it was not until that groove was reduced to 1 inch as a maximum that a satisfactory result was arrived at. Then again, quite recently, cable-tramways had come into successful operation, particularly in Edinburgh and Birmingham, and still later in South London. The width of the slot in those cases was $\frac{3}{4}$ inch, and he could not but think that the large experience that the tramway companies, especially cable-tramway companies had had in the construction of what was adapted to street traffic as well as to haulage, would serve as a precedent for the electric companies, and that they might, with great advantage, consider whether they could not also adopt the $\frac{3}{4}$-inch slot in preference to the 1-inch. He should be glad to know from Dr. Hopkinson whether that reduction to $\frac{3}{4}$ inch was possible or not. With regard to the cost, it should be remembered that street tramcars were the poor man's vehicle, and would not bear heavy expenses; and for that reason undoubtedly the companies would adopt the most economical method, whatever it might be, whether in regard Mr. Shelford

Mr. Shelford. to first cost or the working. What the London County Council would do in regard to tramways in London he could not say; nor could any one tell. They knew, however, that in Glasgow, where the Corporation had for years owned the tramway system, they had lately invited tenders for electrical tramways working on the overhead plan. It was certain that everywhere people wanted to improve upon horses; that they wanted to run more quickly, and to have a more prompt and efficient control of the vehicle, and the system which would do that in the cheapest way was the one that would succeed the best.

Mr. Beaumont. Mr. W. W. BEAUMONT thought the Paper was important, especially with regard to the great question of the cost of haulage on the City and South London Railway, and on other lines. The Author, Mr. Greathead, Mr. Kapp, and other speakers, had referred especially to the curves that were given at pages 224 and 225, and to those prepared and given in a similar form by Mr. Greathead, *Figs. 3* to *6*. Mr. Greathead had prepared them especially to draw attention to the great loss arising from the demand for power for starting the electrical locomotive; and the same demand and the same loss occurred, so far as he knew, on any electrical railways or tramways. The Author, in referring to the questions bearing upon the origin of that demand for power, had touched upon the relative advantages of geared and direct-driving motors, and had arrived at the conclusion that for railways, at all events, direct-driving was the better expedient, though possibly the geared motor was the better form for tramways. All the advantages that he had mentioned on page 218 undoubtedly did and would probably for a considerable time, remain with the geared motor for tramways; but, as far as he could see, it would remain also a matter of importance for the railways too, because the whole of the power referred to by Mr. Greathead as a loss would remain a loss until some means were obtained for starting the motor and its train, without that demand shown by the spikes in the diagram. It had been stated that the difficulty with regard to starting could be overcome electrically; that it was possible to overcome it, either by using a couple of motors in series or more motors, so that it might be overcome by using motors so arranged as to give a very large torque. That was true in regard to overcoming the difficulty of starting at a tolerable speed; but it did not overcome the difficulty that a very great deal of power was required to do that; and that in tramcars, for instance, of quite ordinary weight, it was necessary, or at all events, it was the practice now, to use motors of as high

as 30 HP., the cars not running at a very much higher speed than those ordinarily drawn by two or sometimes three horses. It was, then, necessary to arrive at some arrangement, by means of which the great demand for current at starting could be avoided; and various proposals had been made with that view. If the car could be started by some mechanical means which would enable the relation between the speed of the motor and the speed of the car to be for a few moments reduced—that was, that the ratio of speed of the motor to the speed of the car should be increased, that would get over the difficulty; and instead of requiring 30 HP. to start a moderately heavy tramcar, they might do with much less in proportion to that ratio—say 12 or 15 HP. The subject was one of the greatest importance in connection with the cost of working electrical railways. *Figs. 7* and *8* indicated how the difficulty might be overcome. In *Fig. 7*, A represented a motor-shaft, and A^2 a car-axle, arranged as for single reduction gearing. On the motor-spindle was fixed a double-faced disk-magnet B, current being sent into either of the two energising coils, C or C^1, through the medium of the conductors + + and the return conductor −, according to which side of the magnet it was desired to use. On either side of the double magnet were pinions J and J^1, connected to the armatures H and H^1, the pinions running loose upon the shaft of the motor and gearing with the wheels K and K^1, the one or the other as might be desired. In starting a car current would be sent through the coil C by the conductors + −, and a brush E resting upon one of the collector-rings D. The armature H would thus be drawn to and held by the magnet, the frictional bed being increased by the use of the pole-pieces or rings G, with annular projections fitting into grooves in the armature. The small pinion J would thus be fixed to the magnet and thereby to the motor-shaft, and the car-axle A^2 would be driven at a speed corresponding to the ratio subsisting between the diameter of the pinion J and the wheel K. This in the diagram was a ratio of 4 to 1. The car having been started or having ascended a hill by this means at low speed, the motor running at full speed might now be driven at the higher speed due to the larger pinion J^1 and smaller wheel K^1 by cutting the current out of the coil C and sending it through the coil C^1. The armature H was thus allowed to run loose upon the motor-spindle, and the armature H^1 was fixed to it, and the car would now be driven at the higher speed. This in the case shown would be double the lower speed. An arrangement of gearing for attaining the same end with direct-driven car or railway-axles

Mr. Beaumont

Mr. Beaumont.

Fig. 7.

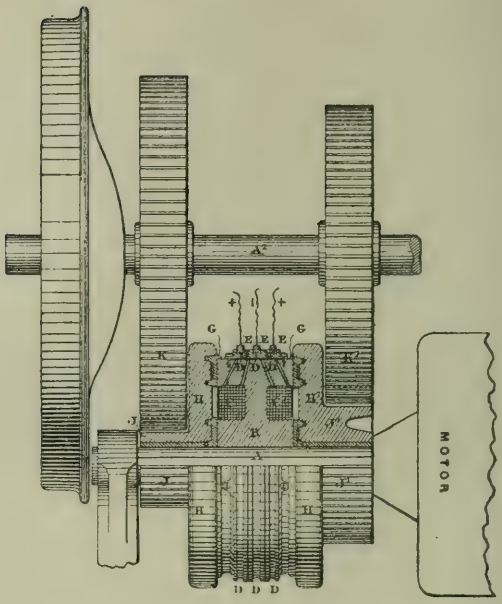
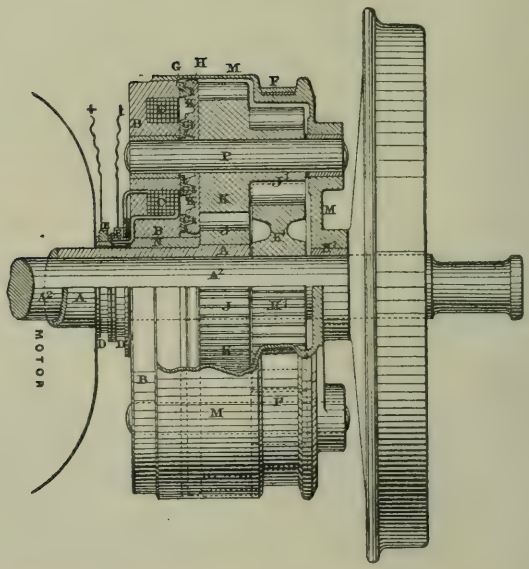


Fig. 8.



was shown in the other diagram, *Fig. 8*, partly in section. In this case the maximum speed was that of the motor, the shaft of which A was hollow, and was mounted and ran upon the shaft to be driven A^2, namely, the car- or railway-axle. Upon the motor-shaft A was fixed a pinion J, gearing into an idle wheel K, carrying a pinion J^1 which geared into the wheel to be driven K^1 fixed to the shaft A^2. Fixed upon one face of the idle wheel K was an annularly-grooved disk-armature H, into which the rings G G on the pole-pieces of the disk-magnet B fitted, forming a magnetic clutch. Two such clutches were employed in the arrangement shown. Current for energising the coils of these magnets was supplied through the conductors + −, the brushes E, and collector-rings D. By means of these magnetic clutches so formed, the idle-wheel K and the connected pinion J^1 might be held fast, and when this was done the shaft A of the motor, the whole of the gearing and containing case were locked together so that the speed of the driven shaft became that of the driving-shaft. For starting an electric car or locomotive, current was cut out of the coils of the magnets B B, and was instead directed into a magnetic clutch-brake not shown in *Fig. 8* (except in so far as the clutch-brake band was shown in section) at F, upon a part of the case M, which is made circular for the purpose. When this clutch-brake F was in action, the case M was held fast, and the idle-wheel K, revolving with the spindle P, drove the car-axle A^2 at a speed which was proportional to the dimensions of the gearing. In the example shown the motor-shaft A would make two and a half revolutions to one revolution of the car- or locomotive-axle A^2. It would be seen that for ordinary running, that was to say, after starting and when not climbing a hill, the whole of the gearing was inactive.

Mr. Beaumont

Mr. Norman Scott Russell said he agreed with Dr. John Hopkinson that the method that was most likely to receive acceptance in this country for tramways was the conduit system, but Dr. Hopkinson did not seem to be well posted up in what had been done with regard to the conduit system, when he mentioned a groove of $1\frac{3}{8}$ inch. He hardly thought that the groove was so wide. At any rate in this country it had been done with a much smaller groove. At Blackpool he understood the groove was only $\frac{5}{8}$ inch. At any rate it was not more than $\frac{3}{4}$ inch at Northfleet. He did not cite either Blackpool or Northfleet as presenting the perfection of underground systems, but there certainly was no difficulty experienced in carrying the electrical current in a groove of only $\frac{1}{2}$ inch. The electrical conduit had this great advantage

Mr. Russell.

Mr. Russell. over the cable, that a third groove was not required. The conduit should be placed under one of the rails so that practically the groove in the rail was a slot. The losses in electrical traction were so many and so great that everything should be made as light as possible. He thought, therefore, that a mistake was made in making the motors for the City and South London Subway on the ends of the cars. Both Mr. Greathead and the Author had said that it was not possible, but Mr. Scott Russell could not conceive why it could not be done. In that way something like 5 tons or $12\frac{1}{2}$ per cent. of the weight would be saved. That would be increasing the efficiency. The coal consumed on the South London line was stated to be 28 lbs. per train-mile,[1] and he might mention that for an ordinary locomotive the consumption would only have been one-fourth, drawing the same weight of train. That showed that where economy only was the object to be attained, electricity was by no means to be preferred. He thought that the Author had done well in adopting the gearless motor. Mr. Scott Russell would advocate that for tramways upon somewhat different reasons from those mentioned by previous speakers. He advocated it because in all mechanical traction, whether by steam, or cable, or compressed air, one of the most serious causes of expense was that of repairs, and he would therefore say "Give me the simplest motor you can—disregard the efficiency." The Americans had adopted with increasing frequency that principle. They began by having duplicate gearing, but they had mostly came to single gearing, and all the great makers—Short, Westinghouse, and Thomson-Houston—were all trying to get a gearless motor. There were, no doubt, difficulties in regard to tramways. There was the difficulty of starting owing to the very low velocity at which the tramway axle ran, about 100 revolutions per minute. In regard to electrical traction on tramways, they must all be glad that the London subways were offering a field for which it was so admirably suited.

Mr. Sellon. Mr. Stephen Sellon said he wished to correct the Author in reference to his statement on page 210 that New York was still without a trolly-road, and the implied inference that it was because the trolly system was inapplicable to so large a city. That, perhaps, might be expected after the attitude which the Author assumed in

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[1] Mr. Scott Russell has since ascertained that on the Underground Railway the weight of train is 150 tons, and the consumption of fuel 34 lbs. per train-mile; so that for a train of 40 tons the consumption of fuel would be 9 lbs., or less than one-third of what is done on the South London line.

the well-known telephone case; but it seemed scarcely consistent with the statement made in the Paper that the only reason that the overhead system was not adopted in the City and South London line was the lack of room. There were at present eighty or ninety cars in operation in New York, which number, although small as compared with other American cities, was about double the number operated in the whole of Great Britain; and that number would shortly be very greatly increased. In Philadelphia concessions had been granted for the trolly on over 100 miles of streets; and if the system was not at present in use, it would be so within a few weeks. The total mileage was also understated. The Thomson-Houston Company alone had 4,700 miles in operation; and the Westinghouse and other systems had about 1,000 miles in operation. He should be glad if the Author would state the name of the conduit road which he had mentioned now running in America, as one of the few, if not the only conduit road, viz., the Love, in Chicago, had now ceased running, due to mechanical defects. He thought that the opposition to overhead wires in England was exaggerated, and that the backwardness in electrical traction was more to be attributed to the deplorable financial condition of nearly all tramways that were not operated under specially favourable conditions. That was largely due to unwise legislation, and, it might also be added, to absurd local clauses. And in many instances the opposition of the Telephone Company, strongly championed by the Author, had prevented the adoption of electricity. In fact, electric tramways would have an uphill struggle until they were accorded the same privileges as railways, viz., carrying all the passengers that they could get, regardless of seating capacity. In fact, the City and South London would not have been able to pay even the small dividend that they had done, had they been compelled to furnish seats for all passengers. The Author had stated that the Buda-Pesth system was a success. For a line to be a commercial success, it was necessary to know what was the original initial cost of the installation, what its earning capacity was, and what was the dividend paid. He was able to supply its earning capacity; that item he had no difficulty in obtaining at Buda-Pesth. He had, however, been unable to obtain any figures as to the initial cost, or as to the dividend paid; and he presumed that the Author was in a position to supply those details which enabled him to state that it was a commercial success; and he hoped the Institution would be supplied with those figures. He thought he had a just cause of complaint when he discovered that the Author stated that there

Mr. Sellon.

Mr. Sellon. had been no interference, due to the use of a trolly-wire system, with the telephones on the City and South London Railway; as, in the lecture which he had recently delivered before the Royal Institution, he stated that there had been a considerable disturbance to telephones by the City and South London Railway, and that he considered that legislation should step in and prevent the use of the single trolly-wire system. That appeared to him rather strange when he remembered that in certain evidence which Dr. John Hopkinson had given in the great telephone case, he had stated, "I think there is no doubt that the one of the two systems in which there was no connection to earth the whole system insulated, would be not only the cheapest, but the most satisfactory in working." That appeared very strange, remembering that the Author had adopted, in every case in which he was responsible, the single-wire system. Dr. John Hopkinson had stated that a conduit for the purpose of electrical traction could be built for £1,500 or £2,000 a mile, and along with that statement he coupled the success of the Buda-Pesth system. He presumed that Dr. Hopkinson did not intend them to understand that the Buda-Pesth conduit cost £1,500 or £2,000 a mile. He wished to make one remark with regard to the Buda-Pesth slot. He had himself measured it upon the ground, and he found it to be $1\frac{5}{8}$ inch. One point, he thought, had been forgotten, viz., that the system at Buda-Pesth had a metallic return—this necessitated the great width of slot in use there, as provision had to be made for insulating the return wire from the other. Mr. Shelford had stated that at Glasgow they had agreed to adopt the overhead system. They did agree to it, but unfortunately it had all fallen through.

Dr. Preller. Dr. Du Riche Preller said that having had a good deal of experience of electrical railways, worked both by locomotives and by motor-cars, he might be allowed to refer to one or two points in relation to the Paper. Had there been time, he would have compared the electrical part of the South London, more particularly, with two lines which he knew very well. As it was, he would confine himself to the tractive force of the motors. One was the steep-grade electrical railway from Florence to Fiesole, with which he had been connected up to last year, and which he had described in a Paper in the Proceedings of the Institution in 1891;[1] and the other was the electrical mountain railway at Mürren, in Switzerland, opposite the Jungfrau, at an

[1] Minutes of Proceedings Inst. C.E., vol. cvi. p. 248.

altitude of 5,000 feet above the sea-level, both being worked by the overhead-wire and trolly system. The Florence line was worked by motor-cars with double gearing, and the Mürren by locomotives which weighed 7½ tons, with single vertical gearing. With regard to the maximum tractive force of electrical motors, that of the Florence motor-cars, weighing 7·5 tons, was 1·5 ton, or one-fifth; that of the Mürren locomotives, weighing 7·2 tons, was as high as 1·8 ton, or one-fourth, and it had been tested up to 2 tons, or one-third, while that of the South London locomotive, weighing 10 tons, was stated to be 1·5 ton, equal to only one-sixth. He would, therefore, ask the Author if, in the figures given in his Paper, viz., 3,000 lbs., or about 1·5 ton maximum tractive force, there was not some inaccuracy, because in hauling a train of, say 30 tons, including the locomotive, up the steepest grade section of 1 in 14, with sharp curves at the Monument end of the line, the resistance the locomotive had to overcome—in other words, the tractive energy the motors had to develop, worked out at 2½ tons, equal to a coefficient of adhesion of one-fourth, such as must be expected from a good electrical locomotive as compared with the coefficient of adhesion of steam locomotives of one-sixth to one-seventh. That brought him to the question raised by Mr. Reckenzaun as to whether the South London locomotives really developed 100 HP. The Author gave the total weight of a normally-loaded train at 40 tons; and, if so, the locomotive would have to develop on the 1 in 14 grade at only 7 miles per hour, not only 100, but 130 HP., equal to 96 kilowatts, or 190 amperes at 500 volts. As a matter of fact, the total train-load was, he believed, only 30 tons, viz., 10 tons for the locomotive, and 20 tons for the three cars with about one hundred passengers. That, at a speed of 7 miles per hour, and taking the coefficient of traction at 13 lbs. per ton, gave 100 HP., or 75 kilowatts, equal at 500 volts to 150 amperes. That agreed with the figures given by the Author, but the discrepancy appeared to be in his train-load of 40 tons and in his maximum tractive force of only 3,000 lbs., and that discrepancy he would perhaps kindly explain. With regard to the remark made by a previous speaker, "Give us simplicity before efficiency," he wondered whether the speaker was aware that in gearless, axle-wound motors repairs were much more troublesome than in single-gearing or in double-gearing, because whenever a motor required cleaning or repairing one axle-wheel had to be entirely dismounted, whereas geared, suspended motors could be much more easily removed or replaced. With reference to the differences in the statements as to the width of

Dr. Preller.

[Dr. Preller. the slot at Buda-Pesth, he thought it must be owing to the circumstance that one speaker measured the width at the ordinary line, where it was 25 millimetres, or rather less than 1 inch, and that another measured it at the points and crossings, which required an extra width.

Dr. Hopkinson. Dr. Edward Hopkinson, in reply, said it was with considerable diffidence that he had brought the subject of the Paper before the Institution, because he was well aware that such an undertaking, in many respects entirely novel and carried out on a large scale, involved much of an experimental nature, which would, nevertheless, in the criticisms to which the Paper would be subject, be treated in the light of subsequent knowledge. But it was for that very reason that he thought that the discussion of the subject might be of special interest, and perhaps not altogether devoid of utility. He joined with Mr. Greathead in regretting that the latter had been unable to bring before the Institution his Paper upon the construction of the railway itself, which was a more weighty matter, and not less novel than the form of traction employed; but he thought the two subjects were so distinct that there had been no inconvenience in the separate discussion of them, or in the circumstance that the Paper now discussed was the first to be read. He would refer to the different points that had been raised in the order of the various parts of the complex machine of which the traction plant of the railway consisted. In regard to the generating-station, he thought that the most interesting remarks on that part of the subject, especially with reference to the loss of efficiency due to the extreme variations in the load, had been those of Mr. Kapp, who had brought forward an important proposal deserving serious consideration, viz., that the excessive load at the moment when several trains were starting together should be met by what he called "fly-wheel motors" placed at suitable points of the line. The proposal had the advantage that it secured the supply of extra power required close up to the work that it had to do. A motor would be fixed at each station or at those stations where the greatest starting-power was required, and so, as it were, in front of the conductors and of the generating dynamos, so relieving not only the engines, but the generating-dynamos and conductors, thereby materially increasing the efficiency. He hoped that Mr. Kapp's proposal would be tried on some future occasion, but he thought that it was worth while for him to consider whether the "fly-wheel" motor should not be put on the locomotive itself, so as to be available whenever it was required.

Such a system had two disadvantages in comparison with the use of accumulators. It did not meet what might be called the diurnal variation in load—the variation between a heavy morning or evening and a light noonday load; it also involved the objection of moving mechanism at places where it could not be easily supervised. They were all much indebted to Captain Sankey for his remarks upon what had been done with the Willans engine; he had thereby added one more favour to the many others which his firm had conferred upon the engineering profession generally, in relation to the theory and practice of the steam-engine. He had shown that the consumption of steam in an engine with a varying load would be approximately the same as the consumption in the same engine working with the mean load. That was a point that Dr. Hopkinson had no opportunity of trying himself, and he thought it was an important point and one of great interest. Much had been said in connection with the use of compound-generator dynamos. He thought there could be little doubt that compound dynamos were the right thing. They were connected through considerable external resistance; the load was seldom entirely off, and there was practically little risk of reversing. To provide against what risk there was, an electro-magnetic arrangement was provided which rang a bell if the current began to reverse, and gave ample warning to the attendant to short circuit the series coils of the dynamo by the switch provided for the purpose; but he believed that that seldom occurred, so that really there was no disadvantage from the use of the compound dynamos. On the other hand, there were very great advantages, inasmuch as it tended to keep the electromotive force on the line much more constant than it otherwise would be. Mr. Kapp expressed some doubt as to whether the generating dynamos really did compound, inasmuch as, on account of the great mass of iron in the field magnets, some appreciable time elapsed before they attained a magnetic state corresponding to the current passing through the coils at the moment. He thought that anything which had led Mr. Kapp to that conclusion was not due to the dynamos themselves, but due to the governing of the engines. No doubt the engines did not govern as satisfactorily as they might do. Any lagging of the electromotive force behind the current was not due to the dynamos, but was due to the engines not adjusting themselves to the load as quickly as they ought to do. Mr. Holroyd Smith had remarked that he (Dr. Hopkinson) was evidently afraid of using compound dynamos because he had provided switches to short circuit the series coils.

Dr. Hopkins

Dr. Hopkinson. The object of the switches was that the dynamos might be properly adjusted to the work they had to do. The dynamo coupled to the near end of the line was worked either shunt or half-compound, but that coupled to the far end was full compound. In regard to another point in connection with the generating-station, Mr. Greathead had drawn attention to a remark in the Paper that there was only one system of steam-pipes, desiring apparently to infer that that was some fault in the original design. As a matter-of-fact he had urged the Company for years to duplicate the pipes, and he was glad to say they were now in such a prosperous condition that they were able to do so. Mr. Holroyd Smith had referred to the switch-board and to the system of cut-outs there employed. He was mistaken in assuming that the current was broken; the current was never broken, but resistance was thrown into the circuit. With reference to the conductor, Mr. Parker had expressed some surprise that he had put it 1 inch below the rail-level, and stated that in Liverpool it had been placed 1 inch above. Mr. Parker was right in the case of the Liverpool Overhead railway in putting it above, because there he had plenty of room; but in the case of the City and South London line the room was exceedingly limited, the clearance below the lowest part of the locomotive being only $1\frac{3}{4}$ inch. It was, therefore, obvious that the conductor must be fixed at the lowest level possible. Much had been said in reference to the effect of the earth-currents upon the telegraph and telephone systems. It was stated in the Paper that experiments had failed to reveal any disturbance. That statement was made on the authority of Mr. Preece himself, the best possible authority in such matters, and was quoted from evidence which he had given on one of the Railway Bills before Parliament. He supposed that in his evidence Mr. Preece referred to the present conditions, and not to those obtaining when the line was first started. That there had been some trouble in the first instance was undoubted, but it had since been entirely obviated. When Dr. Hopkinson referred to the same question in his recent lecture before the Royal Institution, he was not referring to the City and South London line, but to tramway systems in general, and no doubt the disturbance to the telephones had been very serious in many cases. Mr. Preece had taken two sentences in his Paper and put them together, separated from their context. In the one he referred to the return through the rails, which were practically uninsulated, and in the other he said that high insulation was neither

aimed at nor required in the conductor. Mr. Preece took exception to the two statements; but he wished to know to which statement Mr. Preece referred? If he referred to the first, that the rails were uninsulated and the return was through them—practically in that case through the earth—he quite agreed with him that valid objections might be urged against the use of such a system, but of course it could only be prevented by legislation, because the use of an insulated return entailed considerable outlay, which would be avoided unless obligatory. But if it was to his second statement that Mr. Preece objected he could not agree with him, for, given an earth-return a little leakage from the conductor could not in anywise affect the telegraph or telephone systems in the neighbourhood, and therefore from that point of view was immaterial. Mr. Holroyd Smith had asked what was the rule to be followed in determining the size of the conductors. There was only one rule in all such questions which every engineer must follow where possible, viz., Lord Kelvin's, enunciated ten years ago, which he need not repeat. Of course there were instances in which it could not be followed by reason of considerations of first cost; otherwise it was the only canon applicable. With regard to the motors, the most important question of all, he would refer first to the comparison made by Mr. Parker of the motors of the Liverpool Overhead Railway with those of the City and South London line. He thought that Mr. Parker was hopelessly confused between the words "torque" and "tractive force." He had stated that the Liverpool Overhead Railway motors, which weighed $2\frac{1}{2}$ tons each, gave a torque effect of 1,450 lbs., the diameter of the wheel being 2 feet $8\frac{1}{2}$ inches. That corresponded to a tractive force of 1,055 lbs. The motors on the South London line, which weighed $2\frac{1}{4}$ tons each, deducting the wheels, which Mr. Parker did not include in the weight of the motors on the Liverpool line, gave a tractive force of 1,180 lbs. In both cases the current was 100 amperes, so that the City and South London motor gave greater tractive force. Mr. Parker, therefore, instead of having made a great advance in the Liverpool Overhead line had, he thought, taken a retrograde step. Mr. Reckenzaun had asked why Dr. Hopkinson had not given full details of efficiency brake-tests made upon the motors. One reason was that there must be some limit to the length of his Paper. Another reason was, that the theory and construction of motors was well understood by the leading manufacturing firms and did not call for special discussion. There was, however,

Dr. Hopkinson

Dr. Hopkinson. one point that he conceived to be very important, namely, the actual efficiency of the locomotive as a whole, taking into account the loss in resistance, and by reason of the low efficiency at starting. That he had determined, he believed, for the first time, and the result of 70 per cent. as the efficiency of the locomotive as a whole was, he thought, one of considerable interest. Mr. Reckenzaun had expressed some fear that the motors must be of low efficiency on account of the shape of the pole-pieces; but of all the things to which to attribute low efficiency that was the most unfortunate. It would be seen in the Paper that the resistance of the magnet-coils was 0·16 ohm. With a mean current of 70 or 80 amperes the loss would be 12 volts in the magnets out of 500, or about 2 per cent. As the motors were wound with wire of small section, any loss of power due to the shape of the pole-pieces would appear in the amount of magnetizing force required for the magnets. He had shown there only 2 per cent. of the total amount of energy passing through the motors was absorbed in the magnets, so that there was no great margin to turn upon there, whatever the shape of the pole-pieces might be. He would now refer to another point which he was not responsible for introducing into the discussion, but, as it had been introduced, it was necessary to state the facts with some completeness. Mr. Kapp and Mr. Reckenzaun had both referred to the breakdowns which had occurred upon the South London line during the first six or twelve months of working. They did right in referring to them and asking for some explanation. The explanation had been given in general terms that the motors were overloaded; but he agreed that something more definite than that was required, because mere overloading of the motors, although it might reduce the efficiency, ought not to lead to breakdown in an unreasonably short time. When Messrs. Mather and Platt first inspected the tunnels they were in an exceedingly moist and damp state; and they naturally expected that one of the difficulties to contend with would be a damp atmosphere. They accordingly introduced an innovation in the insulation of the wire used for winding the armatures: and between the ordinary two covers of cotton they put a layer of india-rubber. It was well known that india-rubber was an excellent insulator, but that it would not stand any excessive heat; that if it was heated it would sooner or later perish. If the load had been what Messrs. Mather and Platt had been instructed to provide for in the first instance, there would have been no heating of any moment in the motors; but with the materially increased load

there was considerable heating in the wires, and the result was that the rubber insulation was destroyed. Consequently the wires became slack; and where wires were slack sooner or later there must be vibration, and vibration meant the wearing out of the insulation and final breakdown. As soon as he knew that the load was greater than was anticipated, he knew also that every one of the motors would certainly break down, as every one did in due course. But the cure of that had not been what Mr. Greathead suggested—the winding of the motor with a larger section of wire, although that was a proper thing to do from the point of view of efficiency. Mr. Greathead, he thought, could not be aware of what had transpired. Of the thirty-one motors supplied by Messrs. Mather and Platt for working the line, only six had been rewound with a larger section of wire. Yet the other twenty-five worked daily with entirely satisfactory results, simply because they had been rewound with wire without rubber insulation and well shellacked. That was the complete explanation of the breakdowns which had occurred. Mr. Greathead appeared to desire in his speech to give the impression that Messrs. Mather and Platt were aware from the first of what the load would be. Although the point had been referred to in the course of the discussion, he thought that a more specific explanation was necessary. The weight of the carriages originally specified by Mr. Greathead was $4\frac{1}{4}$ tons, and Messrs. Mather and Platt were instructed to provide locomotives of sufficient power for such carriages. Experiments were made about six months after the contract was arranged, not, as Mr. Greathead said, as a condition put upon Messrs. Mather and Platt by the Company, but as an express condition made by Messrs. Mather and Platt with the Company, that they should have the opportunity of making certain tests at an early date. Those experiments were made not with a view of ascertaining what power was required for working the line, because that was a matter of easy calculation, but with a view of testing the novel system of direct-acting motors and other points of detail which it was important should be tested practically before all the locomotives were constructed. Two carriages were supplied for the experimental run, but after the experiments considerable alterations were made in them. The carriages actually supplied for working the line were not those which they had to do with in the experiments, and weighed 7 tons instead of $4\frac{1}{4}$ as originally specified. But whether the experiments were to be directed to the determination of the amount of power required for the line, or whether the carriages

Dr. Hopkinson

Dr. Hopkinson. had been the same then as at a subsequent time, he submitted that so important a change in the fundamental conditions ought not to have been left for chance discovery, but ought to have been announced to the contractors at the first possible opportunity, so that they might have the means of rectifying a calculation which had been made on wrong data supplied. He wished also to refer to what several speakers, including Mr. Reckenzaun, had said with regard to the power of the motors. He entirely agreed with Mr. Reckenzaun that it was a mistake to describe traction motors as of certain horse-power. Traction motors could only be properly described by a statement of the tractive force they would give at various speeds. He had stated that the motors were of 50 HP., not with any object of defining exactly what they could do, but simply with the object of giving a general idea of their capabilities. If they were worked off a 500-volt circuit they would give continuously 50 HP. on the brake at 310 revolutions, corresponding to 25 miles per hour, and in that sense might be described as of 50 HP. He would only refer to one other point: the cost of working per train-mile in lbs. of coal, alluded to by Mr. Scott Russell, who had made a comparison between the 28 lbs. on the City and South London line, and the coal used on large railways. Dr. Hopkinson thought the comparison, although interesting, was not a fair one, because, of course, the conditions of working were entirely different. On such a line as the City and South London every effort was directed towards giving as frequent and rapid a service as possible, and the cost of the coal per train-mile suffered in proportion. Indeed Sir Benjamin Baker had just said to him that it was like comparing a hansom cab with an omnibus, which put the matter more fairly than any words of his own could do. [Mr. Scott Russell said a fair comparison might be made with the Underground Railway.] In conclusion Dr. Hopkinson desired to refer to one point in which Mr. Greathead had forestalled him. It had been a pleasure to him to mention the prominent part which Mr. Mott, the chairman of the company, had taken in the substitution of electrical traction for cable-traction, and his confidence in its success. He had referred to it in his Paper; but such matters, like all not directly relevant, were subject to editorial excision. He regretted that the discussion had not been upon the lines that he thought might have been most usefully followed. It appeared to him that those parts of the scheme which were most susceptible of improvement and open to criticism had been but briefly discussed or altogether avoided; but he thought that the South

London Railway had at least proved that electrical traction could be applied to railways on a large scale with economy, safety, and convenience to the travelling public. Dr. Hopkinson.

Correspondence.

Sir Benjamin Baker, Vice-President, thought that, in order to appreciate the degree of success attained on the South London Railway by Messrs. Mather and Platt, and to give full credit to the directors for their enterprise in adopting the electric system of traction, it was necessary to recall the popular view held on the subject only three years ago. At that time, the general manager of the Metropolitan Railway told a Parliamentary Committee that his company had been negotiating for two years with electrical companies, as they were anxious to get rid of sulphur and other disagreeable concomitants of steam-locomotion on their line, but the results had been so disappointing that he had visited America himself to see what had been done there in the direction of electrical traction. The only really practical experiment, he said, that had ever been made either in the United States or Canada in the direction of substituting electric motors for ordinary locomotives was on the Manhattan Railway in New York. The experiments there cost £20,000, and the electric motor had been at once withdrawn and was lying on the rails rusting and rapidly decaying. According to the official report, he said, the electric motor, at a speed of about 12 miles per hour, cost five times as much as a steam locomotive. Referring to the Report itself, Sir Benjamin Baker found that "the four cars, weighing 59 tons, travelling at a rate of 9·4 miles per hour, excluding stoppages, required a pull of 26·7 net HP.; and to produce this the large generating-engine exerted an average of 175·8 I.HP. Of this, 149·1 HP. was lost in friction, counter-currents, resistance, leakage, transmissions and conversions of power—leaving 26·7 HP. as the net result available for pulling the train. That made the average loss 85 per cent., and the efficiency 15 per cent." He had happened to be in New York shortly after the preceding experiments were made, and his conversation with the Chief Engineer of the Manhattan Railway led him to believe that there was no particular anxiety on the part of that company to attain success with electric-traction, as public pressure might have been exerted to make them withdraw steam-locomotives from their "elevated" lines through the streets of New York and substitute costly electric motors. Nevertheless, Sir Benjamin Baker.

Sir Benjamin Baker.

it was true that, before the opening of the City and South London Railway, these had been the only results which could be quoted of working a railway, as distinguished from a tramway, by electric-traction. To this country, therefore, would accrue the honour of first demonstrating the practicability, from a commercial point of view, of adopting electricity in place of steam-traction on urban railways. He had never entertained a doubt for four years past that, on an underground railway with frequent trains of average carrying capacity, electric-traction would prove at least as economical as ordinary steam-locomotion; and all subsequent experience had simply confirmed that view. The City and South London Railway was, of course, on too small a scale to compare with ordinary railways, but it afforded data for the necessary calculations of the cost of working under better conditions.

Mr. Dickinson.

Mr. A. Dickinson began his experience with electric-traction with the introduction of the accumulator system upon the lines of the Birmingham central tramways. The directors of that company shared the then popular prejudice against electric-traction. Although the company interested in the introduction of electric-accumulator traction upon the lines of the Birmingham central tramways were in favour of using self-contained cars, the directors would not entertain such a proposition, stating that, before they could consider the matter in a serious light, they must have it demonstrated that a separate motor could be built to do the work of a steam-engine. Mr. Dickinson then designed what is known in the Birmingham district as the "Julien" motor. Although this motor was in the aggregate, including cells, less than 7 tons in weight, the power developed by it, especially at starting, was extraordinary. Upon many occasions he had coupled it to a steam-locomotive engine with 9-inch cylinders, 175 lbs. per square inch boiler pressure, with the reversing lever over and steam full on upon a level road, when the electric motor had drawn it backwards. He thought that experiment had convinced the directors of the power of electric motors more than any of the other numerous experiments that were made; and they decided to equip a portion of their line with self-contained accumulator cars which he had designed. The diagram, Plate 5*a*, showed the working of one of these cars upon the Bristol Road, giving the horse-power developed and the speed attained on the various gradients of a section of that line. He had recently introduced on about 8 miles of route, forming part of the South Staffordshire tramways, an overhead system of electric working which is entirely different from anything attempted elsewhere. The system had

only been in use since the first of January, and he could so far speak with confidence as to the results. Mr. Dickinson.

Mr. William Ellis mentioned, in regard to the question of interference caused by the electric railway, that the magnetic instruments proper, at the Royal Observatory, Greenwich, were in no way affected by the railway, but only the instruments used for the registration of earth-currents. There had long been two circuits for the record of such currents—one extending from an earth-plate at Angerstein's Wharf, on the south bank of the river Thames, near Charlton, to another at Lady Well, Lewisham (the line joining these earth-plates being nearly parallel to the direction of the railway), and the other extending from an earth-plate on Blackheath, at the entrance to the tunnel of the North Kent railway, to another at the junction of the North Kent and Greenwich railways (the line joining these earth-plates running in a direction nearly at right-angles to that of the electric railway). The nearest earth-plate to the electric railway was that at the North Kent junction, which was distant from the railway, in a direction perpendicular to it, about $2\frac{1}{2}$ miles. It was found that all cases of magnetic disturbance were accompanied by earth-currents, more or less powerful; when the magnets were quiet, there was practically no earth-current. The character of the interference by the electric railway was such that, whilst trains were running, the needles of the registering galvanometers at the Royal Observatory (one in each circuit) were in a state of continual vibration, commencing daily at about 7 A.M. and terminating at about 11 P.M., but for different intervals on Sunday, corresponding with the train-service. The excursions of the needles did not exceed about one-third of a volt, and were of about equal magnitude in both circuits; and it did not appear that these indications had sensibly changed since the regular opening of the railway. The time-scale on the photographic record being short (about 0·55 inch to an hour) it was not possible to discern on the record the separate motions of the needles. Mr. Ellis.

Mr. L. Epstein dissented from the assertion that "repeated and protracted experiments have proved that, with the types of accumulators at present generally available, the cost of maintenance is prohibitive." The experience gained with accumulators of the Epstein type on the Birmingham Central Tramways Company's Bournbrook line, where they had been in use since August 1892, had proved that not only was the cost of maintenance not prohibitive, but that the low rate of maintenance ($1\frac{1}{2}d.$ per car-mile) not only satisfied the tramway company, but was more than Mr. Epstein.

Mr. Epstein. sufficient to reimburse the charges for the renewal of the positive sections. He might add that during the month of December 1892, owing to the rails being covered with snow and ice, the expenditure of energy was three times as great as it was on the same line in summer; and that on the gradients, it was necessary to discharge at rates up to 200 amperes, from cells whose total capacity was only 170 ampere-hours if discharged at 40 amperes. This proved the capability of the cells to do the rough work required on tramways with steep inclines in severe weather.

Mr. Gibbs. Mr. W. W. Gibbs desired to add some details to the Author's remarks on electric-traction in the United States, more particularly as to what had been done in storage-battery traction. It might be said that battery-traction had been confined to a few experiments carried out by the storage-battery manufacturers. All these had shown that the system was practicable, but had so far failed to show that it was possible to maintain the batteries in working order at a cost acceptable to the railway companies. One type of cell had been tried in New York, two or three in the suburbs of Boston, four or five in Washington, district of Columbia, and one in Dubuque, Iowa. In Philadelphia, probably every battery with any claim to notoriety, whether of home or foreign manufacture, had been tried; but the only one employed actually for commercial service was that known as the chloride battery. The plates composing this cell were cast from fused chlorides of lead and zinc. The zinc chloride was afterwards extracted, the lead chloride being reduced to metallic lead in a crystalline condition. The road upon which this battery was tried was about $3\frac{1}{4}$ miles long, and five cars were run on it for nearly a year. Each car travelled about 80 miles per day. The cars frequently ran 66 miles with one charge. The service was unusually trying, on account of long gradients, some of them as heavy as 6 in 100, and bad curves; but particularly on account of the over-crowding of the cars during certain hours of the day. The cars were of the ordinary 16-feet type, constructed to seat about 20 persons; but 90 persons was a common load, and as many as 117 had sometimes been counted. About 100 cells were used, connected in series; two motors were used on each car, and the various speeds obtained by commutating the motor. The battery, complete with jars and acid, weighed less than 2 tons, and was often discharged at over 200 amperes. Worm-gearing was used, and found to give an efficiency slightly exceeding 80 per cent. This experiment was the first made with this type of cell; and, after working the road for nearly a year, it was decided that the conditions were too

severe for the battery in the state of perfection to which it had at that time been brought. Since then, however, the details of its construction had been much improved, and the manufacturers were prepared to enter into new contracts, and to guarantee results. Mr. Gibbs.

Mr. H. G. GRAVES pointed out that, in the conduit system of electric traction, the conduit might be narrower than it was in cable tramways, where the power had to be transmitted mechanically. The maintenance of the proper width of the slot depended upon the stiffness of the yoke and of the road-bars. Numerous forms of yoke had been employed, and the sections which had recently been put down yielded comparatively little. The cast-iron yokes used on the North Chicago cable lines weighed 416½ lbs., and under a lateral stress of 5,000 lbs. the slot closed 0·155 inch. Some tests made at the Watertown Arsenal with another form of yoke showed a closing of 0·0945 inch under a stress of 5,000 lbs., and 0·1495 inch with 7,500 lbs. Both these yokes carried the slot-bars, and supported the rails also. Though the overhead system of conductors was more convenient in application, English practice tended to put all wires underground. To avoid the difficulties incidental to the open slot, many devices had been proposed. The arrangements might be grouped under several heads. In one form the slot was self-closing, and was only opened whilst the vehicle passed, as in some of the early forms of pneumatic railways. In most of the systems proposed, however, the conduit was entirely closed, so that the main conductor or feeder was completely insulated, and was only connected to a secondary or working contact-conductor in the roadway when the motor-vehicle was passing. Proposals for flexible conduits might be noticed, in which a change of shape, produced by pressure, brought an external conductor into contact with the insulated feeder. By another arrangement, a flexible iron strip in the closed conduit was picked up continuously by an electro-magnet on the vehicle, and completed the circuit. Most inventors, however, had turned their attention to road-contacts which were made in sections and were only connected to the feeder when required, either by electrical or by mechanical means. A large number of this class had been devised, in some of which the circuits were so arranged that one vehicle could not overtake another. These sectional conductor systems were in some cases applicable to a series method of working, in which the successive motors were in series instead of in parallel on the conductors. In another scheme, a long rubbing-surface was carried under the vehicle and Mr. Graves.

Mr. Graves. a number of "jack-in-the-box" contacts were arranged in the road. The number of these switches, often one for each train length, and their delicacy, together with the amount of copper required, would be disadvantageous to the employment of this system. The application of alternating currents had not been alluded to by the Author, but it might be noted that attention was being devoted to their application—a favourite idea being to transfer the energy from the conductor to the motor by induction, so as to avoid the use of travelling-contacts altogether.

Mr. Swinton. Mr. A. A. C. SWINTON was anxious to call attention to the advantages of high-speed engines and dynamos for electric-traction purposes. He wished also to bring forward the question of the practicability of employing motors fitted with fly-wheels, connected across the mains at various points on the line, to act as accumulators in storing energy by acceleration in speed when the load happened to be light, returning the energy to the mains when the load was momentarily heavy. Except in cases where the line was long and the loss on the feeders consequently considerable, such appliances, owing to the loss in efficiency entailed by the double conversion of electrical into mechanical energy and *vice versâ*, and the trouble and expense of maintaining machinery of this kind in isolated positions, might be advantageously replaced by fly-wheels on the main generating-engines, of dimensions and speed sufficient to afford the desired accumulation of energy. Referring to the load curve shown in *Fig. 1*, it might be observed that, if sufficient energy could be stored to give 100 amperes at 500 volts—equivalent to about 66 HP.—for two minutes, it would be possible to run the engines at nearly full load instead of only at about half-load, mentioned in the Paper as representing the actual practice. Engines of the steam-turbine type were coming into extensive use for electric-lighting, and, running at 4,000 to 6,000 revolutions per minute, presented great advantages for all purposes where great and sudden variations in load had to be dealt with. Up to the present time considerable prejudice had existed against engines of this description, chiefly owing to a mistaken idea as to their steam-consumption; but, after several years' experience of their working at the supply station of the Newcastle and District Electric Lighting Company, their adoption for town lighting at Cambridge and at Scarborough, and the trials made by Professor Ewing, such prejudice was disappearing. Taking 4,000 revolutions per minute as the most suitable speed for this class of engine on the large sizes required for traction work, and limiting the allowable variation to 5 per cent., it would be found that a solid

steel fly-wheel, weighing about 6 tons and measuring about 3 feet in diameter and 3 feet wide, which would be safe dimensions for the speed mentioned, would store sufficient energy to maintain 66 HP. for two minutes. Of course when the periods of variation between the maximum and minimum load were less than two minutes, or, again, when a larger variation in speed than 5 per cent. was permissible, such a fly-wheel would compensate for proportionately greater differences between maximum and average loads, or it could be reduced in size. Mr. Swinton.

Mr. F. L. Wanklyn agreed with the Author's remarks about the use of accumulators for electrical traction. They had been tried in America, and, with few exceptions, had been abandoned owing to the excessive cost of maintenance. Moreover, in cold climates, the difficulty of managing wet batteries would be insurmountable. He had had experience of them in connection with the lighting of railway cars by electricity. The system had to be abandoned on account of the difficulty experienced in preventing the batteries from freezing during the intensely cold weather. The trolly system was recognized in America as the only feasible and commercially profitable system of electric traction hitherto developed. The conduit system would be impossible in the Northern States and in Canada, for climatic reasons. Mr. Wanklyn

At Philadelphia a bill had recently been obtained, sanctioning the use of electricity throughout the vast tramway system there; and within a short time, no doubt, the cable system in that city would be a thing of the past; a few miles of electric tramway on the trolly system had already been operated with good results. He would like to know whether any trouble had been experienced from the effect of the electric current on underground gas- and water-mains.

In the City of Boston, which, he believed, had the greatest length of tramways worked electrically in the world, serious trouble was said to have been caused by the corrosive action which is set up in gas- and water-mains by the presence of electric currents. Even in Montreal galvanometers were affected when attached to the water-pipes at considerable distances from the lines of the electric tramway; but, as yet, no serious cause of trouble has been discovered. It was a surprising fact, that in the construction of the City and South London Railway, means had not been devised for rendering the use of an overhead conductor possible. The accidental dropping of a crowbar across the rails coming in contact with the conductor might cause some trouble or danger to anyone attempting to pick it up. With

Mr. Wanklyn. regard to the use of gearless or direct-acting motors, while they no doubt worked satisfactorily on electric railways on which the speed of the vehicles was not limited, they would not be profitable or economical for street-tramway service where low speeds were necessary. Single- and double-reduction geared motors admitted of the vehicles progressing at a low speed, while the armatures could run at a speed admitting of efficiency and economical working. The arrangement of springs on the vehicle would also require careful consideration before any form of gearless motor could be satisfactorily used on a surface railway. There was under construction in Canada an interesting piece of electric railway from Chippewa to Queenston, along the Niagara River, under the direction of Mr. William T. Jennings, M. Inst. C.E. The power for the greater portion of this line would be generated at Niagara Falls by three turbines supplying 1000 HP. each.

Mr. Wanklyn hoped to be able at a future date to lay before the Institution particulars of the working of electric railways in the Dominion of Canada, and the results would, no doubt, afford material for an interesting comparison with the contributions of the Author.

Mr. Wingfield. Mr. C. Humphrey Wingfield observed that when an ordinary watch was brought into the neighbourhood of a motor, there was a risk of its balance-spring being magnetized, and its time-keeping qualities spoiled in consequence. This appeared to him to be a serious objection to systems in which electric-motors were placed on the carriages, and in close proximity to the passengers and their watches. Few people, except electricians, went to the expense of purchasing watches with special non-magnetizable hair-springs, and the effect referred to might prove to be a serious nuisance. In the case of the South London line, the motors being on a separate locomotive, were as far as possible from the passengers, but even on this line he had heard of one case of a watch having been damaged. He wished to ask the Author if it would not be possible to arrange an iron sheath over the magnets, in such a way as to intercept the stray magnetic lines; or in some other way to confine them to the immediate neighbourhood of the motor.

Mr. Volk. Mr. Magnus Volk attributed the slow progress made by electric traction in this country to national prejudice against novelties and restrictive legislation. Accumulators had had much to contend against. The motors first used were not efficient or suitable for the particular work they were applied to. The gearing was defective, the cells were overtaxed, and instead of cars being built

Mr. Volk.

to suit the motors and accumulators, attempts were made to pack them on ordinary cars; and last, but not least, many of the trials were abandoned for financial reasons. Experiments were in many cases made to attract capital; the cars were withdrawn upon some pretext.

As long ago as 1889 he had suggested that the plates should be renewed at a slight profit, so that they might be treated as fuel to last a certain number of hours.

Referring to the City and South London Railway, the non-disturbance of the telephone system in this particular instance, had not prevented the telephone company from opposing all, or nearly all, the electric railway bills in Parliament this year. Direct-acting motors might in this particular instance be quite satisfactory; but it seemed to him that the continuous jolting must be detrimental to the armatures; and although two years' working had not revealed any deterioration from this cause, the question may be asked—had any armature lasted long enough to reveal such deterioration?

In American tramway practice, the preference seemed decidedly in favour of single-reduction motors.

The efficiency of a 20-HP. direct-acting motor, travelling at a speed of 20 miles per hour, was put at 88 per cent., but tram-cars ran at only about 6 miles per hour, which would only give about 70 revolutions per minute. What would the efficiency be then? It was this latter efficiency that should be compared with single-reduction gearing, to say nothing of the decreased weight of the geared-motor.

LIST OF MODELS AND APPARATUS

EXHIBITED AT THE MONTHLY RECEPTION, 21 FEBRUARY, 1893.

Exhibitors.	Objects.
J. Wolfe Barry, M. Inst. C.E.	Photographs (6) of the works of the Tower Bridge.
O. Berend & Co.	"Berliner" 8-pole watch-receiver.
	Set of telephone-engineer's tools.
W. S. Boult, Assoc. M. Inst. C.E.	Model of magnetic thrust-reliever for propeller-shafts.
	Photograph and description of proposed system of electric traction for tramways.
City and South London Railway Company.	Map of proposed electric railways in London.
	Plan of City and South London Railway Company's line and stations.
	Section of conductor.
Crompton & Co.	Electrical heating- and cooking-apparatus.
Alfred Dickinson, Assoc. M. Inst. C.E.	Diagram and photographs (2) of electric bogie tram-car.
Drake & Gorham . . .	Cell for launch and tram-car work.
	Section of ditto.
Easton & Anderson . . .	Models of tramway-rails.
	Photographs of electrical tram-cars.
Elliott Brothers . . .	Astatic galvanometer (portable).
	Resistance coil (Post Office pattern).
	Smith's decimal wire-gauge.
	Standard cell.
Fowler-Waring Cables Company.	Telephone cables.
General Electric Company	"Hunning's cone" microphone and telephones.
W. T. Goolden & Co. . .	Photograph of electric hauling-engine.
J. W. Gray & Son . . .	Lightning-conductors.
P. W. O. Hodges, Assoc. M. Inst. C.E.	Ampere-meter.
Edward Hopkinson, D.Sc., M. Inst. C.E.	Photographs of the City and South London Railway electrical plant.
L. F. MacLean, M. Inst. C.E.	Working model of the shutters and crane used on the Chenab Weir, India.
Manchester Edison-Swan Company.	"Fawcus-Cowan" dynamo.
Nalder Brothers & Co. .	Reading telescope.
	Transparent scale.
	Various electrical apparatus.

Exhibitors.	Objects.
National Telephone Company.	By permission of Mr. D'Oyly Carte and Mr. Horace Sedger, this company placed the rooms of the Institution in communication with the Savoy and Lyric theatres, by which the members were enabled to hear selections from "Haddon Hall" and "The Magic Opal."
James Pitkin	Electrical chronograph. Electric bell. Galvanometer. Recording ammeters.
C. P. Sandberg, Assoc. M. Inst. C.E.	Set of Sandberg's standard rail-sections.
Arthur W. Sclater, Assoc. M. Inst. C.E.	Distributing-board.
Siemens Brothers & Co. .	Ammeter. Electro-dynamometer. Voltmeter.
A. A. C. Swinton, Assoc. M. Inst. C.E.	Photographic enlargements (2) of electrical discharges.
Western Electric Company.	Switchboard for Exchange use. Telephones and component parts.
William H. Winterbotham	Bell's earliest form of telephone.

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21 and 28 February, 1893.

HARRISON HAYTER, President,
in the Chair.

The Discussion on the Paper on "Electrical Railways" occupied both evenings.

Sect. II.—OTHER SELECTED PAPERS.

(*Paper No. 2599.*)

"The Zurich Water-Supply, Power and Electric Works."

By Charles Sheibner Du Riche Preller, M.A., Ph.D.,
Assoc. M. Inst. C.E.

PART III.—THE POWER-SUPPLY AND ELECTRIC WORKS.

In Part I[1] of this communication, the Author gave an account of the Zurich Waterworks. He proposes to supplement that by a description of the plant employed for the supply of power and electricity to the Town of Zurich. These works form an integral part of the waterworks pumping-station, because, as formerly explained, the motive-power and apparatus employed is arranged so that the balance of the power developed over and above that required for power- and electric-supply purposes may be used for pumping. This power is, as stated in Part I, 1,036 HP.; of which 237 HP. are employed in pumping potable water, the pumps in operation being seven in number, one of which raises water alternately to a high-pressure service-reservoir, and to a hydraulic accumulator tank in connection with the power-supply. There are also three pumps in reserve, the entire set being driven by ten turbines, illustrated in Figs. 2 and 3, Plate 6.

I. Supply of Motive-Power.

At Zurich motive-power is supplied for industrial purposes in three ways: (1) by wire-rope transmission, (2) by hydraulic pressure, and (3) by the filtered-water supply, for small motors. The power supplied by the first two systems is utilized exclusively by the mills and factories situated in the "industrial quarter," on the left bank of the Limmat, opposite the pumping- and near the filter-station; where the Corporation owns about 50 acres of land, which it lets for industrial purposes at a ground-rent of 8*d.* per square yard, in order to dispose of its surplus motive power as long as it can be spared.

(1) *Power by Wire-Rope Transmission.*—This power is generated by either the turbines already mentioned in connection with the

[1] Minutes of Proceedings Inst. C. E., vol. cxi., p. 257.

waterworks, or those to be subsequently described when dealing with the electric works. It is then transmitted by means of rope-towers, of which the first (No. 1) is placed in the machine-house of the pumping-station (Figs. 1 and 4, Plate 6), in the space between the pumping- and the electric-machinery. By means of a vertical shaft, coupled by gearing to the main shaft, the power is transmitted to the rope-pulley on the top of the tower, by a rope 328 feet in length spanning the river, to tower No. 2 on the left bank; from here, on the one hand, to towers Nos. 3, 4, 5, and 6 up the river; and, on the other hand, to towers Nos. 7, 8, 9, 10, 11 and 12 down the river. Up the river, the transmission of power does not, at present, extend beyond towers Nos. 3 and 4, about 820 feet; whilst the transmission to the five towers down the river extends 1,686 feet. At the normal rate, the velocity of the rope is 65·6 feet per second. Power by rope-transmission is at present supplied to four works, viz., a flour-mill, a silk-mill, dye-works, and machine-works; the total amount being 227 HP., mean, and 246 HP., maximum, developed at the main shaft. The total cost of the installation, including towers, gearing, connections in the industrial quarter and sundries, was £9,200, equal to about 20*s.* per yard of transmission; the receipts being about £1,320 per annum, or £6 per HP. supplied. It is probable that, before long, when this power will be required for the water-supply, electric wires will be substituted for the rope-transmission.

(2) *High-Pressure Hydraulic Power.*—This power is supplied by a hydraulic accumulator—an open tank, situated about a mile north-east of the pumping-station—the capacity of which was at first 98,886 cubic feet, but has recently been increased to 353,170 cubic feet, and is to be further increased to 529,750 cubic feet. It stores water derived from the old Limmat filter-bed and conduit, and is charged by the set of pumps which raise also potable water to a high-pressure reservoir, situated to the south-east of the pumping-station; the water is generally pumped during the night and distributed by day, under a head of about 475 feet, through main and distributing-pipes of a total length of about 15,584 feet, in the industrial quarter. Here, by means of small turbines, it supplies power to telephone-, dye- and finishing-works, printing-works, metal-ware factories, corn-elevators, and other works. The charges for the supply of this power vary from 0·6*d.* to 1·25*d.* per horse-power per hour; the former minimum rate being for more than 50,000 metrical HP.-hours, the latter for less than 20,000 metrical HP.-hours. The water thus supplied, exclusive of the extension for electrical purposes, is about 42,380,000 cubic feet per annum, corresponding to about 900,000

metrical HP.-hours. The total receipts are about £1,200 per annum, equal to about 1·08*d.* per 1,000 gallons. The cost of the hydraulic accumulator-tank was £4,000; and that of 15,584 feet of pipes, valves, and hydrants, £8,260.

(3) *Power by Potable-Water Supply.*—This power, which, as part of the potable-water supply is pumped by the plant illustrated in Figs. 1, 2, and 3, Plate 6, specifically described in Part I of the Paper under "The Zurich Waterworks," is distributed throughout the town and suburbs to about 180 small motors, from ½ HP. upwards; comprising, besides a great variety of small trades, several electric-installations, hotel-lifts, and church-organs. The total thus supplied is about 187 HP.; the annual receipts amounting to about £2,200, equivalent to 4·4*d.* per horse-power per hour. Besides this motive power, the waterworks supply filtered water for general industrial purposes to over 1,300 works and factories, as well as to the three railway-stations and to the Abt rack and wire-rope railway, which connects the lower with the upper town, and on which the descending cars carry water to counterpoise the ascending cars. The supply for these industrial purposes is about 31,785,000 cubic feet per annum, the receipts being about 4*d.* per 1,000 gallons.

II. The Electric Works.

The rapid growth of the use of electricity for private purposes in Zurich, both for motors and lighting, amounting in 1890 to 47 installations with 48 dynamos, and to 493 HP. supplied by water-power as well as steam- and gas-engines, recently induced the Corporation to undertake the electric-lighting of the town and suburbs on its own account; especially as the motive-power could, in preference to steam- or gas-engines, be advantageously provided by the waterworks, which also offered a convenient site for a central supply-station.

(1) *Motive-Power.*—The installation, Figs. 1 and 4, Plate 6, is designed for a first supply by high-tension alternators with transformers, of 10,000 60-watt glow-lamps (to be subsequently increased to 20,000) for private lighting, and 130 arc-lamps of 900 watts each, for public lighting, leading from the central railway station to the lake (Rue de la Gare and Limmat quay), nominally. The generating-power required is therefore about 934 HP., supplied by hydraulic power as follows:—

590 HP. by two high-pressure turbines actuated by high-pressure water.
344 „ by two reaction-turbines actuated by ordinary (Limmat) water-power.
There are also two steam-engines of 296 HP. each in reserve.

As a matter of experience, however, not more than two-thirds of all the glow-lamps burn simultaneously, even at the time of maximum consumption; and in Zurich this is the case in the winter months, when the arc-lamps on the ornamental lake quays are reduced to one-half; whilst, on the other hand, the maximum consumption of the arc-lamps falls in the summer months, when the demand for glow-lamps for house-lighting drops to the minimum. The two supplies therefore compensate each other, and the actual generating-power required may be taken at 533 HP. Hence, either the two high-pressure turbines, or one high-pressure turbine, and the two reaction-turbines can adequately meet the demand for generating-power during the few hours of greatest consumption; whilst during the hours of minimum consumption, one high-pressure turbine or the two reaction-turbines suffice. The motive-power of the two high-pressure turbines, together with two small high-pressure turbines of 30 HP. for actuating the exciting-dynamos, is derived from 444 HP. available high-pressure water-power, accumulated to 735 HP. by storage, giving, at 88 per cent. efficiency, 651 HP. in respect of the direct-driven dynamos; whilst the 2 reaction-turbines (also available for pumping-purposes) are actuated by the Limmat water-power amounting to 430 HP., giving, at 80 per cent. efficiency, 172 HP. each.

(2) *Central Supply-Station.*—As already stated, this station constitutes an integral part of the pumping-station of the waterworks. The high-pressure turbines and dynamos are placed at one end of the building, whilst the two reaction-turbines and the two reserve (horizontal compound) steam-engines occupy the space between the electric machinery and the pumps; being at the same time placed in proximity to the rope-transmission tower, so as to be available either jointly or separately, as may be required, for pumping, rope-power-transmission, or electrical purposes. To this latter end the whole of the electric machinery is arranged symmetrically about the main shaft, Fig. 1; which, for this purpose, is carried 41 feet beyond the reaction-turbines, XI and XII, its diameter being 7·6 inches. As this main shaft makes only 100 revolutions per minute, whereas the dynamos make 200 revolutions, a separate shaft for the high-pressure turbines and the dynamos is placed at a distance of 5 feet 3 inches from the main shaft. Thus the two high-pressure turbines, provided with automatic regulators, drive the four alternate-current high-tension dynamos, on the same dynamo-shaft to which the main shaft, by gearing of 1 to 3, transmits additional power derived

from the reaction-turbines or steam-engines. By means of friction-couplings, the dynamo-shaft can be worked in three parts, jointly or separately,—namely, two parts, each of which can be driven by one of the high-pressure turbines utilizing the hydraulic accumulated power for night-service; and the third part for day-service, utilizing the power of the reaction-turbines (or reserve steam-power) transmitted by the main shaft. When the dynamo-shaft is coupled as a whole, the high-pressure turbines act not only as a complement to the power transmitted by the main shaft, but also as effectual regulators for constant speed. The four alternate-current dynamos give, at 200 revolutions per minute, 100 amperes at 2,000 volts per dynamo, or a total of 800,000 watts. They are excited by two small high-pressure turbines actuating two exciting alternate-current dynamos of 30 HP., each working on the same shaft, and making 400 revolutions per minute; from which the power is transmitted by gearing to the main shaft and thence to the dynamo-shaft. The indicators and regulators are mounted on the lower end wall of the building.

(3) *Distribution.*—The main and subsidiary cables are, at the outset, designed for a supply of 20,000 glow-lamps. The primary cables, laid in a brick channel about 2 feet below the surface of the ground, consist of four concentric high-tension (2,000-volt) cables, 40 millimetres (1·575 inch) square in cross section, from the central- to the distributing-station in the centre of the town. The distributing-station[1] consists of a masonry hut, 20 feet by 10 feet, from which radiate the secondary main cables, also laid in brick channels, leading to eighteen transformer-stations; these being circular iron boxes 3 feet 3 inches in diameter, and 9 feet 10 inches in height, containing altogether 44 transformers, which convert the high-tension current of 2,000 volts into low-tension currents of 100 to 200 volts for both house-supply and street-lighting. Both the primary and secondary cables are composed of single insulated copper wires, varying between 25 and 250 square millimetres (0·039 to 0·387 square inch) in section, with a double lead covering. Three secondary mains are always laid in one brick channel, the centre cable being for safety connected to earth in all transformer-stations. The arc-lamps for street-lighting are mounted on standards 23 to 26 feet high, placed at equal distances apart of about 197 feet. The sections

[1] On the right bank of the Limmat, at a distance of about 2,420 yards up the river from the electric works, and 440 yards below the bridge.

of the copper cables are calculated from the formula $Q = \frac{2\,l \times J}{60 \times E}$; Q being $> \frac{J}{2}$, in which Q is the section in square millimetres, l the distance from the transformer in metres, J the current in amperes, and E the loss of tension in volts; a margin of 20 per cent. being added, and the sections being rounded off to current dimensions between 25 and 250 millimetres square as mentioned above; whilst sections between 350 and 500 millimetres square are formed by combining smaller sections. The loss of energy being 5 per cent. between the dynamos and transformers, and 7 per cent. between the transformers and lamps, the energy of a glow-lamp of 60 watts is reduced to 53 watts, or 0·26 ampere; and that of an arc-lamp of 900 watts to 791 watts, or 4 amperes, at the point of consumption. The guaranteed efficiency of the transformer is 95 per cent. when fully, 92 per cent. when one-half, and 86 per cent. when one-quarter, loaded; and the loss when running unloaded is not to exceed 3 per cent. of the total capacity, which is 20,000 watts for each transformer. The 44 transformers therefore have a total capacity of 880,000 watts, sufficient for a maximum supply of 15,000, 18,000, or 20,000 lamps, according as the whole, three-fourths, or two-thirds, are lighted simultaneously.

(4) *Cost of Installation, Rates, and Working.*—The cost of installation designed for 10,000 glow- and 130 arc-lamps, including the electric machinery and distribution, but exclusive of the building, hydraulic machinery and steam-engines debited to the waterworks, is £48,560; equivalent to £628 per arc-lamp of 900 watts, including standard and lamp; and about £4 3*s*. per incandescent lamp of 60 watts. The total annual working expenditure, including interest and sinking fund, is £12,000; of which £3,480, for the 130 arc-lamps (235,600 hours), and £8,520, for 10,000 glow-lamps (5,000,000 hours)—being about 3·6*d*. per arc-lamp,[1] and 0·4*d*. per glow-lamp per hour. Hence the rates fixed for the supply of private (glow-lamp) lighting, based on a price of 0·76*d*. per unit, vary from 8*d*. to 4·25*d*. per lamp per hour, the mean being 0·6*d*. per lamp per hour for 1,000 hours, exclusive of the first cost of lamps and fittings,

[1] Compared with gas, the cost of installation of the arc-lamps is considerably less than, whilst the working expenditure is about 100 per cent. more than, gas; but the illuminating-power of the former is five to ten times greater than that of the latter. The price of gas at Zurich is comparatively high, viz., 10·65*d*. per 100 cubic feet; in some other Swiss towns, it is as low as 2·75*d*. per 100 cubic feet.

and of the wear and tear, which amounts to about 0·05*d.* per glow-lamp, and 1*d.* per arc-lamp per hour. The rates include an annual fixed meter-charge of 8*s.* for each lamp. These rates are 20 to 30 per cent. higher than those charged for the gas supplied by the Corporation gasworks, and were so fixed with a view to protect the latter against injurious competition. The rates charged for electric-lighting in other Swiss towns are very similar to those of Zurich; *e.g.*, at Lausanne 0·72*d.* plus an annual charge of fr.36; at Vevey-Montreux, 0·42*d.*; at Geneva, 0·5*d.* per lamp per hour; while at Lucerne, a fixed charge of 16*s.* is made per 10-candle lamp per annum. The receipts from the 130 arc and 10,000 glow-lamps are £14,640 per annum; the net surplus, after allowing for interest and sinking fund, is £2,640; and the total return on the capital expenditure of the electric-installation, properly speaking, is 13·6 per cent.

The special committee appointed by the Corporation recommended the erection of the installation proposed by the Oerlikon Works, near Zurich, which accordingly supplied the electric-machinery; while Messrs. Escher, Wyss & Co. of Zurich, furnished the hydraulic machinery; Messrs. Sulzer Brothers of Wintherthur the steam-engines; and Messrs. Berthoud, Borel & Co. of Cortaillod, near Neuchatel, the cables, standards, arc- and glow-lamps, transformers and accessories.

III. Water-Supply and Electric Works (Summary).

In Appendixes I and II the Author has compiled the totals of the cost of construction and working, as well as the rates for the water-, motive-power, and electric-supply, together with the growth of consumption of potable water in relation to the growth of population, since the introduction of the filtered lake-water supply. The average rate of 3·5*d.* per 1,000 gallons, for potable water, is low, although not lower than that of other Swiss towns. From the detailed returns of the gross earnings (average of 1889 and 1890), the percentages of the daily consumption for different purposes, appear to be as shown in Table on next page. The total net cost of the water- and power-supply, and the electric-supply, up to the present time, exclusive of £40,000 for extensions of filter-station, reservoirs and distribution, to be carried out within the next few years, is about £426,000; of which about nine-tenths are represented by the water- and power-supply, and one-tenth by the electric-installation. The average return on the capital is about 6·7 per cent. in respect of the waterworks, and

13·6 per cent. in respect of the electric works. The annual expenditure for extensions, or the annual increase on capital account since the introduction of the filtered lake-water supply, is about £4,000—almost 1 per cent. of the original capital of £320,000. The growth of the population of Zurich and its suburbs has been, during the 5 years 1885 to 1890, 2 per cent. per annum; whereas the increase of consumption of the filtered lake-water has been 6 per cent. per annum during the same period.

—		Daily Consumption.		—
		Total.	Per Head of Population.	
	Per Cent.	Gallons.	Gallons.	
For potable and domestic purposes	14	666,000	6·5	Spring water.
	52	2,442,000	27·0	
For industrial purposes	14	666,000	6·5	Filtered Lake water.
For small motors	14	666,000	6·5	
For public purposes	6	289,000	4·5	
For motive-power (hydraulic)	..	732,000	..	Old Limmat filter.
For electric lighting	..	2,220,000	..	Old Limmat filter.
For motive-power (rope-transmission)	..	999,000	..	Computed as hydraulic power.
Total	100	8,680,000	51·0	

This part of the Paper is illustrated by drawings from which Plate 6 has been prepared.

APPENDIXES.

APPENDIX I.

RATE OF CONSUMPTION OF WATER.

—	Population.	Percentage of Population Served.	Average Supply per Head of Total Population.	Annual Increase of Lake-Water Consumption.
		Per cent.	Gallons per Day.	Per cent.
1885	85,787	76	42	..
1886	87,889	77	46	7·0
1887	89,991	78	47	5·0
1888	90,693	80	48	1·2
1889	92,651	85	50	14·0
1890	94,000	86	52	3·0
Average . .	..	..	..	6·0

APPENDIX II.

EXPENDITURE AND REVENUE OF WATER-SUPPLY, POWER-, AND ELECTRIC WORKS.

—	Capital.	Gross Revenue.	Expenditure.		Net Revenue.
	£.	£.	£.	Per cent.	£.
Water-supply and power- .	352,624	28,657	5,036	18	23,621
Do. do. extension .	24,840				
Electric works	48,560	14,640	8,000	55	6,640
Totals . .	426,024	43,297	13,036	30	30,261

(*Paper No. 2638.*)

"Westport Harbour Works, N.Z."

By John Alexander Wilson, Jun., Assoc. M. Inst. C.E.

The Westport harbour works, for facilitating the export of coal, are situated at the mouth of the Buller River, on the west coast of the South Island. The basin of this river has an area of 2,340 square miles, with an average rainfall of 95 inches.[1] The minimum discharge is 157,500 cubic feet per minute; and the highest recorded flood, in November, 1879, registered 7·75 feet above H.W.S.T. at the upstream end of the wharf; while an ordinary flood rises 5 feet above the same level. The average velocity of the river when low is 1·4 foot per second near Buller Bridge, and slightly less at the wharves.

The works for improving the entrance, and the tidal portion (Figs. 1 to 7, Plate 7), were thus described by the late Sir John Coode:—

> "The west breakwater would . . . run at the outset in a northerly direction, gradually curving therefrom so that the outer portion shall point N.N.W., until reaching the proposed termination . . . the total length, from high-water mark of ordinary spring-tides to the end, being 4,400 feet. The east breakwater would extend in a north-westerly direction, curving therefrom towards the east, the outer portion being parallel to the western work, and the entrance between the breakwaters being 600 feet."

The west breakwater was designed to overlap the east breakwater by 400 feet, to provide for the travel of the beach in an easterly direction. These two breakwaters are now completed, the first stone of the works having been laid in 1884. The interior works consist of training-banks, coal-loading appliances, dredging, and a proposed dock. The main training-banks on the west side of the river are about to be undertaken, a short one on the east side having been made some years ago; some dredging has been done; and coal staiths have been erected (Figs. 1, 2, 8 and 9). A railway, 6 miles 68 chains in length, had to be constructed from the quarries to

[1] Report on Westport Harbour Works, by Sir John Coode, December, 1880.

the west breakwater, with a branch 4 miles long to the east breakwater. Tip-wagons, specially designed for these works, carry loads ranging from 25 tons on some of the side-tip wagons with three axles, to 12 tons on some of the end-tip wagons with two axles. The wagons were mounted on springs owing to the distances they had to travel; and, in order that the centre of gravity of the load should not be unduly high, the rails on which the weight was concentrated were hung below the axle-boxes.

Quarrying.—The breakwaters are formed of granite, gneiss and limestone, from the Cape Foulwind quarries. To obtain stone for the works in large blocks, and cheaply, it has been broken out by large blasts, thirty of these blasts having been fired. The charges for this class of work were carefully considered in relation to the form of the rock to be blasted, Figs. 10 and 11, sometimes very irregular, and in relation to its nature, which also varies considerably, from bedded and jointed gneiss to homogeneous masses of granite. On an average, 1 lb. of dynamite dislodged 10 tons of stone; and the total amount of a charge was usually decided on this basis, the separate charges being proportioned in the ratio of the cubes of their least resistances, L. R. ÷ 35 for dynamite, 36 for gelegnite, 43 for gelatine dynamite, 50 for blasting-gelatine, and 12 for blasting-powder. These quarries being worked for large rubble to be used in positions exposed to heavy seas, very large blasts (entailing as they generally do, long lines of least resistance) have not answered. A blast containing 3 tons of explosives, and also one of 7 tons, were each in their way failures. Even if such a blast was successful in bringing down its complement of stone, that in the neighbourhood of the charges was so broken up as to be completely spoilt; and the site of such a blast may, from the same cause, be ruined as a quarry. On these works, blasts containing from $\frac{1}{4}$ of a ton to $1\frac{1}{2}$ ton of explosives have been found the most useful; and this class of blasting hardly answers with a line of least resistance much exceeding 40 feet; beyond that, the elasticity of the rock, along the line of least resistance, becomes too great for the resistance of the back off which the charge works, and, instead of throwing the front out, the explosion may merely develop an undulating motion radiating from the charge. The best results were obtained where the rock had one or more loose ends, with a nearly vertical face; a strong toe at the quarry floor-level being usually removed by hand-blasting before firing the large shot. The length of the adit was made as nearly half the height overhead as practicable; while the most even results were obtained if $1{\cdot}5 \times$ least resistance was

adopted for the intervals between the chambers, and even less with irregularly shaped blasts. An improved splice for the fuse, Fig. 12, was found to lie closer, and was less likely to cause a miss-fire than the common splice. The fuse used was instantaneous sub-marine fuse, igniting at the rate of 60 feet per second, to which about 3 feet of time fuse was attached. One great advantage of these fuses over electric wires is that any working foreman can manipulate them.

Breakwaters.—Stone was first tipped on the west breakwater in June 1886, and on the east breakwater in June 1888; and both breakwaters were finished in April 1892.[1] The lengths of breakwater completed each year, with the number of tons of stone in each portion, and the cost per lineal foot, are given in Appendix I. An entrance has been left between the breakwaters of 700 feet at L.W.S.T., instead of 600 feet. The breakwaters have been once seriously damaged by a very heavy sea, together with a flooded river, on August 2nd, 1890, when three bays of the staging on the west breakwater were demolished, and two bays were damaged; while, on the east breakwater, five bays were washed away, causing the loss of pile-driving derricks and movable staging on both breakwaters, and the overthrow of a 5-ton crane, subsequently recovered in a damaged condition. The damage, costing £3,000, was caused by drift timber from the river being driven against the outer piles by the force of the sea, and breaking them; and the wreckage thus formed completed the injury during high-water of one spring-tide. The mound of the west breakwater has had its toe dragged forward, and its base widened by the sea. The mound of the east breakwater has not suffered thus, being less exposed.

The foreshore advanced rapidly behind both breakwaters during their progress; but this movement is diminishing rapidly, principally owing to the deeper water reached, and also because the promontory of Cape Foulwind, with its outlying rocks, "The Steeples," cuts off most of the littoral drift; and the encroachments that occur consist solely of sand. Deep water is maintained at the outer end of the west breakwater, Fig. 5, Plate 7, having followed it out almost from the first. For a distance of 200 to 250 feet in front of this breakwater, and for about its own bottom width in breadth, there is a depth of 30 to 45 feet at L.W.S.T., as against the normal depth of 23 feet in the neighbourhood.

[1] It has since been determined to place a fringe of 8,000 tons of stone along the slopes of the breakwaters, at a cost of £1,333, to maintain them against the continual scour.

This has increased the cost of the work, owing to the depth of the foundations; but it is favourable for the maintenance of the channel, for the strong currents which set round the end of the work, sweep the sand drift from the west into such deep water as should prevent silting at the entrance. Though the waves may aid in producing this deep water, it is largely due to the scour of currents; for when, on one occasion, a strong current set round the end of the breakwater during its construction for some days, 10 feet had to be added to the length of the next piles pitched. Some observations made lately, round the heads of the breakwaters, indicate currents near the bottom, varying with the stages of the tide, but averaging a velocity of $\frac{1}{4}$ mile per hour. The observations were of necessity made in fine weather; in bad weather, the velocity would be greater.

The advance of sand behind the east breakwater seems due to local slack water, or a slight return-current near the shore, caused by the works acting as a groyne; it is not expected to give serious trouble, as there is no general littoral drift of sand or shingle from east to west, and the set of the river and tidal currents round the end of the works tends to prevent the growth of the foreshore beyond a certain point.

The stone covering the outer side-slopes, and the rounded end of the west breakwater, ranges between 10-ton and 30-ton blocks, and on the exposed slopes of the east breakwater, between 10-ton and 20-ton blocks. The outer 600 feet of the west breakwater, and the outer 1,350 feet of the east breakwater, were built from staging, which has great advantages over working from a tip-head in point of the facilities it affords for placing the different classes of stone in the positions where they will be most useful. The piers, 25 feet apart, have piles to each pier; and there are 3 lines of way on the staging, one over each pile (Figs. 6 and 7). The piles were driven by a pile-driving derrick, supported on cantilevers projecting over the previous row of piles; and one 5-ton steam-crane drove the piles and lifted the timbers. One complete bay could be erected on the east breakwater in a week, and one bay in a fortnight on the west breakwater, where the water was deeper. In the worst weather this staging was always perfectly secure, merely requiring the wedges to be tightened up in all fastening-chains before the storm became severe.

The *teredo navalis* has completely honeycombed the piles of the staging on the east breakwater, where the mound has only been constructed to half-tide level (Fig. 6); and the staging has had to be temporarily shored up. Some piles of New Zealand black

birch became much weakened from this cause six months after they were driven. As the scour along the river side, and round the end of this breakwater, causes continuous settlement of the rubble mound, permanent securing of the staging is contemplated, to enable the tipping of the stone for the maintenance of the mound to be continued. The present form of the rubble mounds at the outer ends of the two breakwaters are shown on Figs. 4 to 7; but their final slopes will probably be somewhat flatter.

Dredging.—Details of the dredging plant, and of the amount and cost of the dredging, are given in Appendix II; while the form of the dredged channel is shown on Figs. 8 and 9, Plate 7. The bottom consists of shingle and sand, sometimes almost cemented together, but generally loose. Under the shingle, 18 to 20 feet below low-water spring-tides, there is a stratum of very tough blue clay, through which the dredging has not penetrated. A gridiron was constructed for the repair of the dredging-plant, and to serve for part of the foundations for a patent slip; its sill is 1·20 foot above low-water spring-tides, and has 7·90 feet of water over it at high-water spring-tides, so that work can be carried on at a vessel's bottom for 5 hours during springs, and 3½ hours during neaps.

The dredging was much hampered by timber buried in the river bed; and a pair of shear-legs, to lift 40 tons, erected on the dredger, raised these obstructions, being worked by the forward steam-winch. Many methods for making fast to submerged logs have been tried. A steel-headed spear, with jagged edges, about 2½ inches by 1 inch in section at the shoulder, and fitted into a 1½-inch wrought-iron tube, plugged at the other end to take the blows of a sledge-hammer, has proved most useful, logs weighing up to 5 tons having been lifted in this way, until slings were got beneath them from the dredger. Timbers too large, or too deeply embedded to be raised, have been slung by a diver, or blasted into smaller pieces to be removed by the Priestman dredger. Very heavy trees have been chained to the steam-barges at low-water, and lifted by a rising tide.

Coal-Loading Appliances.—Coal is always loaded at this port from elevated staiths, Fig. 8, 1,150 feet in length, 20 feet above high-water of spring-tides at their upstream end, and 35·60 at the downstream end, the steepest gradient being a short one of 1 in 60, and the flattest 1 in 206. They contain 36 bins, having 19 shoots, and a storage capacity of 2,000 tons. The lips of the bins and shoots (to which telescoping shoots are hinged) vary from 7¾ feet to 25¼ feet above high-water of spring-

tides, the shoots being the higher of the two. The staiths are approached at their upstream end by an incline with five lines of way, two of which, with a gradient of 1 in 44, run the full wagons up from the station-yard, while the empties are returned down the remaining lines into sidings. They can load vessels as fast as the trimming is accomplished; and 380 tons are often put into a vessel in one hour, whilst on the average, including trimming, the rate varies from 200 tons to 250 tons per hour. The loading is performed for $2\frac{1}{2}d.$ per ton; and this simple system is cheap, as regards first cost, compared with a complete hydraulic or steam-crane plant; whilst the storage afforded is of advantage where the tonnage is fluctuating, and the rolling stock required is small. The disadvantage of this system is the liability to break up the coal, and lessen its value.

Results.—The deepening already effected at the entrance by the breakwaters is indicated by a diagram, Fig. 13, and by the Table below. The slight shoaling last year, as compared with the year before (Fig. 13), is probably due to an unusually dry season, with a rainfall of only 68 inches, and to a quantity of material, loosened by the continuous dredging, being carried by the outgoing current over the bar. Taking the actual range of tide, $9\frac{1}{2}$ feet, instead of 11 feet as originally assumed, the full depth of water anticipated may now be said to have been obtained.

Depths available for Navigation.	Before Commencement of Works.			During Progress of Works.				
	1883–84	1884–85	1885–86	1886–87	1887–88	1888–89	1889–90	1890–91
Feet. Feet.	Days.	Days.	Days.	Days.	Days.	Days.	Days.	Days.
8 and under 10	41	51	29	54	18	..	..	..
10 „ „ 12	164	219	218	246	169	..	..	..
12 „ „ 14	140	91	109	63	144	..	..	..
14 „ „ 16	20	4	9	..	25	14	8	..
16 „ „ 18	1	..	..	..	4	108	61	..
18 „ „ 20	..	..	..	..	4	151	98	55
20 „ „ 22	..	..	..	..	2	88	105	117
22 „ „ 24	..	..	..	..	..	4	70	126
24 „ „ 26	..	..	..	..	..	..	22	50
26 „ „ 28	..	..	..	..	..	..	1	11
28 and over . .	..	..	..	..	..	..	..	6

The deepening at the entrance is specially felt in the much greater number of days on which the bar is smooth, so that a vessel in the roadstead in bad weather is rarely unable to cross the bar at high water, which formerly was a frequent occurrence. The improvement in the tidal portion, caused by the breakwaters and by dredging, is also manifest (Fig. 2). Careful observations taken at Buller Bridge, during six months, show that the low-water level has already fallen 4 inches, owing to the deeper water secured in the tidal portion.

The total cost of the works has amounted to £340,427, some details of which are given in Appendixes II and III.

Mr. C. Napier Bell, M. Inst. C.E., was the engineer for the first three and a-half years; then Mr. A. E. Austin, Assoc. M. Inst. C.E., had temporary charge for a few months. Mr. F. W. Martin subsequently conducted the works until 1891, under the late Mr. W. Blair, Engineer-in-Chief, and the late Colonial Marine Engineer, Mr. C. Y. O'Connor, MM. Inst. C.E.; the works have been since carried out under the Author.

The Paper is illustrated by six sheets of tracings, from some of which Plate 7 has been prepared.

APPENDIXES.

APPENDIX I.—Progress and Cost of Breakwaters.

West Breakwater.

Period.	Lengths.	Contents.	Cost per Lineal Foot.
	Feet.	Tons.	£
April 1, 1886 to April 1, 1887	1,056	50,803	9
„ „ 1887 „ „ „ 1888	1,782	196,815	15
„ „ 1888 „ „ „ 1889	707	141,190	39
„ „ 1889 „ „ „ 1890	382	131,157	51
„ „ 1890 „ „ „ 1891	230	102,555	118
„ „ 1891 „ „ „ 1892	119	36,037	106[2]
Totals	4,276[1]	658,557	..

East Breakwater.

Period.	Lengths.	Contents.	Cost per Lineal Foot.
	Feet.	Tons.	£
June 12, 1888 to April 1, 1889	2,425	81,016	4
April „ 1889 „ „ „ 1890	1,535	87,880	8
„ „ 1890 „ „ „ 1891	484	47,344	37
„ „ 1891 „ „ „ 1892	292	44,700	35[2]
Totals	4,736[1]	260,940	..

[1] The shorter length is accounted for by the high-water mark having advanced since the survey of 1879 on which the design was based, which rendered it unnecessary to construct the full length of 6,000 feet.

[2] The apparent anomaly of a smaller price per lineal foot under a greater exposure, is due to the much larger class of stone obtained out of the high-level quarry lately opened out; the stone available immediately prior thereto, being too small to resist the action of the sea, was driven about and did not advance the works. The stone during the last period has also been obtained at an unusually cheap rate.

APPENDIX II.—Dredging-Plant, and Cost of Dredging.

Dredging Plant.

	Original Cost. £.
One Centre-Ladder Dredger.—Length, 138 feet; breadth, 23 feet; depth at ends, 10 feet; depth amidships, 9 feet; draft forward, 4½ feet, aft, 7½ feet. Compound engines, 35 nominal HP. Bucket ladder, 72 feet centres, with thirty-six buckets; bucket-capacity, 6·75 cubic feet. Dredging in 26 feet of water, it lifts 200 tons per hour. Speed, 2½ miles per hour	13,475
Two Steam-Hopper Barges.—Length, 130 feet; breadth, 21 feet. Length of hopper, 43½ feet; breadth of hopper at top, 15½ feet; Capacity of hopper, 200 tons. Speed, 5½ miles per hour, with engines similar to those in the dredger . . . . . each	9,220

Amount and Cost of Dredging.

Place.	Period.	Tons.	Cost per Ton.
			s. *d.*
In fairway[1]	1889	2,120	1 9
At wharves and staiths[1].	1889 and 1890	15,360	1 7
In fairway	1891	52,818	0 9
At wharves and staiths	1891 and 1892	207,912	0 8
		278,210	

[1] Executed with less complete plant than that now in use.

APPENDIX III.—Cost of Works.

	£.
Plant[1]	70,251
Western breakwater	123,043
Eastern breakwater	50,108
Dredging	12,767
Wharves, and staiths extension[2]. . . .	20,000
Cape Foulwind Railway and branches .	49,158
Buller Bridge	15,100
Total	£340,427

[1] The dredging-plant was purchased second-hand for £12,000; its first cost was as given in Appendix II.

[2] The actual cost of the last coal-staiths extension was £26 per lineal foot.

(*Paper No. 2568.*)

"The Khojak Rope-Inclines."

By Walter James Weightman, Assoc. M. Inst. C.E.

At the time when it was decided to construct a railway across the Kwaja Amran range, on the Afghanistan frontier of India, three rival projects were under consideration; and it was at first regarded as an objection to the route finally selected, that the tunnel, which formed its chief feature, would require three years in construction. The Government of India deemed it to be of paramount importance to establish railway communication across the range at a considerably earlier date. Under the circumstances, and pending the completion of the tunnel, it was determined to construct a temporary railway, rapidly and cheaply, over the mountains, and the inclines about to be described formed part of this work. The completion of the tunnel has necessarily been followed by the dismantling of the temporary inclines, which, owing to their steep gradients and diversity of system, exhibit some features of interest; and the details of their construction, their cost, and working expenses, may be worth placing on record before they are forgotten. Their object was twofold: first to facilitate the conveyance of machinery and stores for the western end of the tunnel, and to expedite the extension of the railway beyond it; and, secondly, as a military precaution, to provide for the conveyance of troops and military stores to the front in case of need. It was deemed essential that, whatever system was adopted, it should be possible to transport intact broad-gauge (5 feet 6 inches) locomotives, wagons loaded with stores, and other rolling stock for a possible advance.

When submitting the scheme, the points which had to be borne in mind were therefore:—(1) That, as the lines were to be used for three years only, they must be constructed as cheaply and as quickly as possible; (2) that they should be of broad gauge throughout; (3) that the inclines should be able to carry the heaviest broad-gauge locomotives and rolling stock; (4) that, in order to avoid delay through obtaining plant and appliances

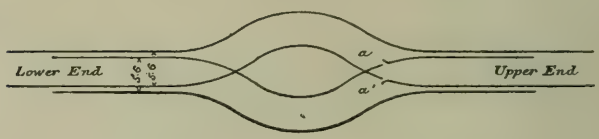
from England, they should be so designed that they could be made in India; (5) that the carrying capacity should be not less than 400 tons per day.

All the temporary lines and inclines are shown in section in Fig. 1, Plate 8, from which it will be seen that the first portion of the temporary line leaves the permanent line on the east side of the range at Shamshakhan, and follows the river-bed on an average gradient of 1 in 22 as far as Shelabagh. Here the slope of the valley steepens, and the gradient, as far as Wallers Camp, is 1 in $15\frac{1}{2}$, with curves of 500 feet radius. Six-wheeled locomotives, weighing 46 tons exclusive of tender, hauled, as their ordinary load, 4 wagons, weighing 72 tons, as far as Shelabagh; and thence to Wallers Camp the line was worked with specially designed eight-coupled tank-engines fitted with brakes (hand, steam, and Le Chatelier) on all the 8 wheels; the coupling-rods being joined together with ball-and-socket joints, to increase their flexibility on curves. These engines weigh 50 tons, and, taking a load of 54 tons up 1 in 15 gradients round 500-feet curves, did their work extremely well, running regularly 5 to 20 trains daily each way for three years.

The gradients of Nos. 1 and 2 were so steep (35 and 40 per cent.) as to require the use of two specially-designed incline-trucks, in order to prevent the loads in the wagons from shifting (Fig. 2, Plate 8). These are so constructed that their upper platform, on which a pair of broad-gauge rails is laid, is always horizontal during transit. The ordinary loaded wagons are carried on the top of these incline-trucks, being shunted on at the bottom and off at the top, and *vice versâ*. No. 1 incline, worked by a stationary engine and wire rope, rises with a gradient of 1 in $2\frac{3}{4}$ till it reaches the summit of the range, a height of 7,260 feet above sea-level. Next follows a short length of single broad-gauge line (5 furlongs) along the ridge, with a ruling gradient of 1 in 40, worked by small tank-engines; and then commences the descent of nearly 2,000 feet on the west side. This is achieved by three separate rope inclines, the first having a gradient of 1 in $2\frac{1}{2}$, the next of between 1 in 7 and 1 in 10, and the third of between 1 in 8 and 1 in 13. These three inclines are succeeded by a short length of single line, with a gradient of 1 in 16, which was worked by tank engines with eight-coupled wheels, similar to those on the east side. This line joins the permanent railway close to Chaman Fort; whence the latter has been laid, with a ruling gradient of 1 in 40, for a distance of 10 miles, down to the terminus at New Chaman.

The total length of the four inclines is 2 miles and 830 feet. Details of the gradients, lengths, and heights surmounted, are given in Appendix I. Nos. 1 and 2 inclines are worked in the usual way by a steel-wire rope driven by a stationary engine at the top, one truck ascending as the other descends, the two passing each other in the centre; but the arrangement of the lines of rail was unusual. As shown in *Fig. 1*, it consists of two separate tracks on the upper and lower portions of the incline, with their centres only 6 inches apart, and a crossing-place in the middle. The advantages of this plan are:—(1) the great saving in cost over a double line for the whole length; (2) the elimination of the danger due to movable or self-acting points, which occurs if a single line is laid on the top and bottom sections; and (3) the simplicity of the approach-lines at the foot and summit of the incline; because, by placing the rails on the incline-trucks (Fig. 2, Plate 8), 3 inches to the right for the left-hand truck and 3 inches to the left for the right-hand truck, a single line suffices at both ends of the

Fig. 1.



incline to shunt the wagons off and on to the trucks. It is not unusual with inclines such as these, to lay three rails on the upper section, the centre rail being common to both tracks, in order to provide against the danger of one truck fouling the rope of the other; but on the Khojak incline that would have largely increased the cost and the time of construction, because there is a cutting in hard rock 45 feet deep on the upper section, and also the arrangement of lines and turn-tables at the top would have become somewhat more complicated. With the arrangement used, although at the points a and a' the wheels of the ascending truck have to pass over the rope of the descending truck, and *vice versâ*, it was found that the rope invariably dropped into the gap in the rails prepared for it, being assisted in so doing by tapering wooden guides (Fig. 6, Plate 8).

The permanent way consisted of 75 lbs. flat-footed steel rails laid on wooden sleepers; and, to prevent the rails slipping down hill, a cast-iron chair was fixed at each joint, as shown in *Fig. 2*. This chair was bolted to a timber balk, 12 inches by 12 inches,

which again was bolted to a block of concrete. The horizontal rollers, *Fig. 3*, were placed 30 feet apart on the straight and 15 feet apart on curves; they were 6 inches in diameter, made of babool wood, but were found to wear away so rapidly that it became necessary to cover them with thin sheet-iron. Vertical rollers, *Fig. 4*, were used at the centre crossing place only, as the rest of the incline was straight.

The winding engines used (Figs. 3, 4 and 5, Plate 8), were converted from old locomotive engines, with inside cylinders 16 inches in diameter and 24 inches stroke, taken off their wheels and mounted on cast-iron standards, bolted down to a masonry foundation. The motion is transmitted through spur-gearing, which reduces the speed to one-tenth; the second set of gearing consists of three wheels and pinions, which were stepped each a third of the pitch in advance of the other; this plan made the

Fig. 2.

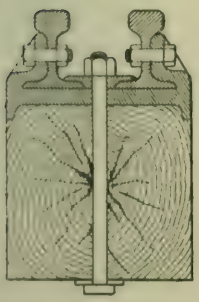
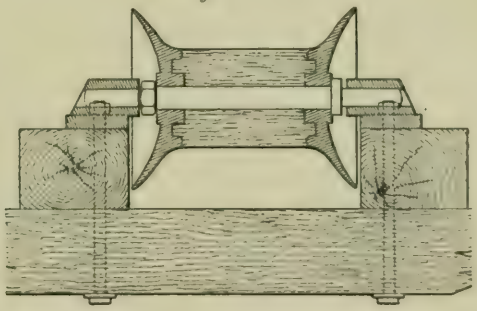


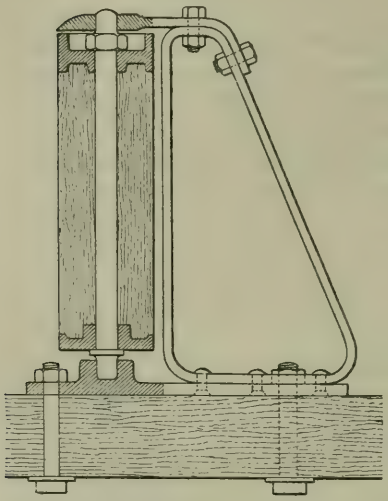
Fig. 3.



working very smooth. The hauling-rope, 4½ inches in circumference, with a breaking load of 80 tons, and a maximum working load of 13 tons, of extra plough-steel, is passed round a Fowler clip-drum, 10 feet 6 inches in diameter, round which it takes two-thirds of a turn only. This plan was adopted because of its simplicity, and has worked very well. An ordinary winding-drum would have been very large, and would have necessitated two ropes instead of one. At first the clip-drum gave some trouble, as the jaws which grip the rope were constantly breaking. But after the cause of this had been discovered and removed, they worked uniformly well, and were not found to squeeze or flatten the rope. The normal speed of the engine was 100 revolutions per minute, which gave a speed of 4 miles per hour to the trucks; it was fitted with hand- and steam-brakes. The details of the steel ropes and the work they performed are shown in Appendixes

IV. and V; from which it will be seen that the Lang patent ropes showed, in a marked way, their superiority for this sort of work. The ropes originally used were those made in the ordinary way, with the lay of the strand in the opposite direction to the lay of the rope; but it was found that the wires broke very rapidly at the crown of the strand. Then Lang ropes were tried, in which the strands of the rope are closed in the same direction as the wires are laid; and they were found to do 50 per cent. more work than the others, and were still working when the inclines were dismantled. The works being temporary, and intended only for goods traffic, although eventually many thousands of passengers did make use of the inclines, it was not considered desirable to go to the expense of any special automatic safety-appliances, and none were used. No accident of even the slightest kind occurred, the precaution of changing the ropes in good time being always taken. The quality and reliability of steel-wire ropes have so far improved of late years, and their price has so decreased, that there is not the same inducement to keep them running when they have become dangerously worn, and the old feeling of distrust in rope inclines is not nearly as prevalent as formerly.

Fig. 4.



Inclines Nos. 3 and 4 call for no special description; they were laid with double lines throughout the whole length, because, owing to the valley being more open, the earth-work was very light; and the traffic over this portion being all down-hill, they were made self-acting. Horizontal pulleys, 12 feet in diameter, were fixed at the summits of each incline, fitted with double hand-brakes. In the centre of No. 4 incline there was a curve of 1,146 feet radius, 1,400 feet long, and the vertical rollers for this curve were placed outside the track on the concave side, in the way proposed by Mr. Longridge,[1] and were found to work quite satisfactorily.

[1] Minutes of Proceedings Inst. C.E., vol. lxiii. p. 114.

The total cost of the four inclines amounted to £28,699; the details of expenditure being shown in Appendix II. The monthly working-expenses are given in Appendix III. The cost of haulage will be seen to have been 1*s.* 9*d.* per vehicle-mile, which at first sight may appear somewhat high if compared with that of the São Paulo inclines[1]—1*s.* per vehicle-mile, or with that of the Calstock inclines[2]—1*s.* 3*d.* per vehicle-mile; but as the vehicles used on the Khojak lines carry more, a fairer comparison is obtained by considering the cost per ton-mile, which is as follows:—

—	Per Gross Ton-Mile.	Per Paying-Ton-Mile.
	d.	*d.*
Khojak	1·615	3·23
São Paulo . . .	1·40	2·40
Calstock	2·28	4·29

The grades on the Khojak inclines are, however, much steeper than on the others, and, as pointed out by Mr. Robert Wilson, M. Inst. C.E.,[3] in the case of railways with steep gradients, a much more satisfactory comparison can be made by comparing the cost per 1,000 foot-tons of work done (goods carried) in each case. On this basis the cost is:—

—	Per 1,000 Foot-Tons. Gross Load.	Per 1,000 Foot-Tons. Paying-Load.
	d.	*d.*
Khojak	1·824	4·06
São Paulo . . .	2·60	4·50
Calstock	2·96	5·77

The traffic on the Khojak inclines, Appendix VI, was mainly in one direction, and most of the wagons returned empty; if there had been any freight in the opposite direction, the cost of haulage would have been much less. On the other hand, it is right to call attention to the fact that the traffic was up one incline only and down three; this, of course, kept the working expenses and fuel-consumption unusually low. The maximum day's work was

[1] Minutes of Proceedings Inst. C.E., vol. xcvi. p. 165.
Railway Engineer, April, 1881.

[2] "Cost of working the Hartz Mountain Railway." Minutes of Proceedings Inst. C.E., vol. xcvi. p. 134.

53 wagons in each direction; every wagon held 11 tons of goods, consisting chiefly of railway material and stores.

The works were constructed by the Author, under the instructions of Mr. F. L. O'Callaghan, C.S.I., C.I.E., the Engineer-in-Chief; the designs and drawings having been first submitted for approval to Sir Guilford Molesworth, K.C.I.E., the Consulting Engineer to Government. All the machinery and appliances were made at the North-Western Railway locomotive and carriage shops at Lahore, under the directions of Mr. C. Sandiford, M. Inst. C.E.

The communication is accompanied by 4 tracings, from which Plate 8 and the *Figs.* in the text have been prepared.

APPENDIXES.

APPENDIX I.—Details of Inclines.

—	Gradient.	Length.	Vertical Height.	Maximum Load Hauled.	Observations.
		Feet.	Feet.	Tons.	
No. I. .	1 in $2\frac{3}{4}$	1,320	452	30	Crossing-place in centre.
No. II. .	1 in $2\frac{1}{2}$	1,420	568	30	Crossing-place in centre.
No. III. .	1 in 7 1 „ 8 1 „ 9 1 „ 10	3,950	484	40	Double line, self-acting.
No. IV. .	1 in 8 1 „ 12 1 „ 13	4,700	376	50	Double line, self-acting.

Total length of inclines . . . . . 2 miles 830 feet.
„ „ including all connections . 4 miles.

All inclines 5 feet 6 inches gauge.

APPENDIX II.—Cost of Inclines.

Heads of Expenditure.	Amounts in Rupees.
Rock-cutting	43,180
Shale „	21,053
Earth-work	25,241
Retaining-walls	9,180
Bridges	2,173
Ballast	4,924
Permanent-way material	91,360
„ „ laying	15,438
Wooden sleepers	6,775
Permanent-way, masonry, struts, balks, &c.	23,076
Buildings, staff-quarters, engine-sheds, &c.	18,665
Carriage turn-tables	29,665
Winding-engines, complete	52,018
Pulleys, rollers, wire ropes, &c.	25,609
Incline-trucks	12,128
Miscellaneous machinery	4,926
General charges and contingencies	16,380
Total cost of 4 inclines . . Rupees	401,791
Equivalent to	£28,699

APPENDIX III.

COST OF WORKING THE INCLINES.

Monthly Expenses.

Nature of Expenditure.	Amount in Rupees.
Establishment—Foreman	350
,, Drivers, &c.	700
,, Workshop	200
,, Labour, &c.	1,600
Fuel—coal, 50 tons @ Rs.15	750
,, wood	150
Oil and small stores, &c.	500
Material for repairs, &c.	250
Contingencies	100
Total monthly expenses	Rs.4,600

15 wagons daily each way = 3,600 vehicle-miles per month.
Cost of haulage = 1*s.* 9*d.* per vehicle-mile, or 3¼*d.* per (net) ton per mile.
NOTE.—The above is for an average month when traffic was brisk.

APPENDIX IV.

DETAILS OF ROPES USED.

Inclines Nos. 1 *and* 2.

—	Maker.	Circumference.	Number of Wires.	Weight per Fathom.	Cost per cwt.	Breaking Load.	Working Load.
		Inches.		Lbs.	£ *s.* *d.*	Tons.	Tons.
1st rope.	Bullivant.	4½	114	19	2 5 0	74	No. 1—11½ ,, 2—13
2nd ,, .	,,	4½	114	19	2 5 0	74	,,
3rd ,, .	Craddock (Lang's).	4½	114	19	3 7 0	80	,,
4th ,, .	Bullivant (Lang's)	4½	114	19	2 2 0	80	,,

Incline No. 3.

1st rope.	Bullivant.	4⅝	72	13·8	2 0 0	40	4
2nd ,, .	Craddock (Lang's).	3	36	8·5	2 15 0	36	6

Incline No. 4.

1st rope.	Bullivant.	4⅝	114	13·8	2 0 0	50	5

APPENDIX V.

Work done by Ropes.

No. 1 *Incline.*

—	Date when put on.	Date when taken off.	Gross Tonnage Hauled.	
			Ascending.	Descending.
			Tons.	Tons.
1st rope .	Sept. 10th, 1888.	Aug. 2nd, 1889.	74,300	48,890
2nd ,, .	Aug. 2nd, 1889.	May 5th, 1890.	78,500	50,890
3rd ,, .	June 25th, 1890.	Aug. 31st, 1891.	116,160	77,440
4th ,, .	Not required—3rd rope still working when the inclines were dismantled.			

No. 2 *Incline.*

1st rope .	Dec. 10th, 1888.	July 27th, 1889.	46,249	70,130
2nd ,, .	July 27th, 1889.	June 22nd, 1890.	57,749	87,130
3rd ,, .	June 25th, 1890.	Aug. 31st, 1891.	75,220	111,830
4th ,, .	Not required—3rd rope still working when the inclines were dismantled.			

No. 3 *Incline.*

1st rope .	Feb. 1st, 1889.	July 31st, 1891.	51,788	84,744
2nd ,, .	Not required—1st rope still working when the inclines were dismantled.			

No. 4 *Incline.*

1st rope .	June 5th, 1890. Still working when the incline was dismantled.	Aug. 25th, 1890.	24,277	39,726

APPENDIX VI.

NET TONNAGE OF STORES CARRIED, CONSISTING CHIEFLY OF RAILWAY-MATERIAL, PERMANENT WAY, BRIDGE-WORK, STATION-MACHINERY, TIMBER, COAL, BRICKS, SAND AND CEMENT, &c.

Year.	1st Quarter.	2nd Quarter.	3rd Quarter.	4th Quarter.	Total of Year.
	Tons.	Tons.	Tons.	Tons.	Tons.
1888	..	..	..	2,222	2,222
1889	5,368	13,893	8,844	7,953	36,058
1890	9,570	5,533	18,832	11,737	45,672
1891	4,169	5,060	2,255	..	11,484
			Total tons (net) carried		95,436

Maximum month's work . . . . . 5,588 tons.
„ day's „ . . . . . 583 „

(Paper No. 2650.)

"Regulating the Rate of Filtration through Sand."

By Professor William Kinnimond Burton, Assoc. M. Inst. C.E.

The different and sometimes apparently contradictory results that various experimenters in sand filtration have arrived at, whether the tests for purity before and after filtration are biological or chemical, seem to indicate that all the factors of successful filtration are not thoroughly understood. Mr. B. Nojiri, Chief Engineer to the Osaka Waterworks, was occupied with elaborate experiments on the effects of varying the speed of filtration at the time of his death early in 1892. The results of these experiments will probably be published at some future time. Meanwhile it may be of interest to know that the results of biological tests were different from those of chemical tests. Thus, as the velocity of filtration was reduced, the purity of the water, as chemically tested, increased until a velocity of 20 lineal feet in 24 hours was attained; but as the velocity was further reduced, the filtration, as indicated by chemical tests, became less efficient. In the case of biological tests, on the other hand, the number of bacteria decreased till the speed of filtration was reduced to 10 feet in 24 hours, beyond which point there appeared to be no advantage in reducing the velocity.

Whatever filtering velocity may be the best, it would appear to be essential to efficient filtration that the velocity should be kept uniform, and it would seem that engineers have scarcely given to this matter the attention that it deserves. Any arrangement for accurately regulating the velocity of filtration is frequently absent from published designs of waterworks. The necessity for such an arrangement was pointed out by Mr. James P. Kirkwood 25 years ago, and he adopted a movable sluice with the water flowing over the top for regulating the speed of filtration. He pointed out that, where there were several filter-beds, it was desirable to have a regulating arrangement for each one. Mr. Henry Gill, M. Inst. C.E., has several times described an ingenious arrangement adopted for this purpose at the Berlin Waterworks. One of the simplest methods of regulating the speed

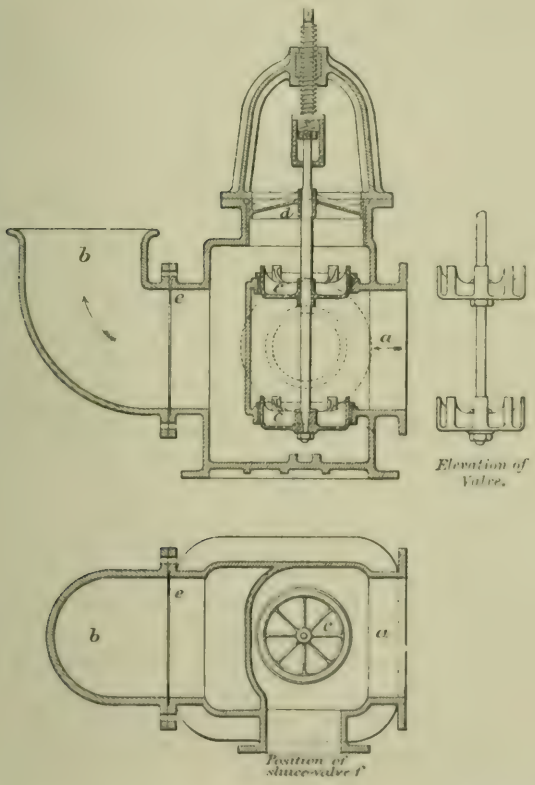
of filtration is by the use of a telescopic tube on the discharge-pipe from the filter. This pipe is so arranged that its upper end can be raised to the level of the water in the filter-bed. In this case no water will flow through the sand. By lowering the level of the pipe a "filtering-head" is produced, and this "head" may be altered as appears necessary from time to time from the sand becoming gradually clogged. For the Nagasaki Waterworks, the Author designed an arrangement consisting of 3 telescopic pipes, one on the outlet of each of 3 filter-beds, all arranged in one well. A filter can be filled with filtered water from below by lowering the telescopic tube as far as possible, and partly closing the valve on the outlet of the well. The water from the other filter-beds then backs up in the discharge drain. The reason for filling the filter-beds from below, at any rate until the water covers the sand by 2 or 3 inches, is that, before the water has reached that level, the rate of filtration is quite out of control, with the water admitted in the ordinary way—only a small portion of the sand-bed near the admission pipe actually being in use.

The Author, being engaged in the early part of 1888 in designing a waterworks for Tokio, in connection with which filtering will have to be conducted on an extensive scale, paid considerable attention to means of regulating with precision the flow of water through the filters. He premised as essentials for a perfect system of regulating the discharge from filter-beds :—

(1) It shall be possible to adjust the filtering to any determined speed, and, once adjusted, the speed shall remain constant, even if the head necessary to overcome the friction of the water passing through the sand varies; (2) it shall be possible to fill the filter-beds from below with filtered water; (3) the waste of water in cleaning out filter-beds shall be reduced to a minimum; (4) the apparatus shall indicate when a certain maximum head for overcoming the friction of the filter-bed has been reached. The valve arrangement shown in *Figs. 1* was designed to effect these purposes. The water enters the valve from the filter-bed at *a*, and is discharged into the filtering-well, which is in connection with the clear-water reservoir, at *b*. The balanced valve *c* is controlled by a piston *d*, the upper side of which is open to the water in the well. The arrangement is similar to that of a reducing-valve. The object is to keep the difference of pressures in the valve-body and the clear-water reservoir constant. If this is done, the discharge through the whole apparatus, which passes through a circular orifice in a movable diaphragm *e*, will be constant.

If the discharge tends to exceed that decided on, the pressure inside the valve-body, against the under side of the piston *d*, increases, the piston rises, and the balanced valve is partially closed. If, on the other hand, the discharge tends to decrease, the pressure on the inside of the diaphragm and on the under side of the piston decreases, the piston and valves fall by gravity, and the flow is increased. A small hole is made through the

Figs. 1.



piston to prevent the accumulation of air below it, which would disturb the working. The slight leakage through this hole does not materially influence the working of the valve. The quantity of water to be passed may be determined either by the size of the diaphragm or by the weight of the piston and valve. The piston and valves with spindle are weighed in water. This weight divided by the area of the piston gives the differential pressure at

the diaphragm, and it is a simple calculation to find what diameter of aperture is necessary to pass a given quantity of water with this pressure. When the valve drops on the bottom of the casing, it is an indication that the head due to the difference of level between the water in the filter-bed and that in the well is needed to overcome the friction of the water passing through the sand, and that the filter needs cleaning. It is customary to clean filter-beds at fixed intervals of time, but it would probably be more economical to let each bed work until a certain head of water was necessary to overcome the friction of the sand. An indicator could easily be fitted to the valve so that the dropping of the piston should be made apparent above the surface of the water in the well. A screw-spindle for actuating the valve by hand is shown in the drawing.

The action of the whole arrangement is as follows:—The level of the water in the filter-bed is kept uniform by an automatic valve that it is not necessary to illustrate, as its principle is well known. The velocity of the flow is, as already described, kept constant by the automatic action of the valve, until the filter-bed has become clogged to a certain extent. The valve then drops to the bottom of the body. If now, the flow of water into the filter-bed be stopped, what is above the sand will slowly drain away, none being lost. When it has so drained away, or when it is desired to stop the operation, the valve is closed by screwing it up by hand. The sluice-valve *f* is then opened, and the water, as far as is considered necessary, is allowed to run to waste. In filling, the valve is depressed by hand, and the filtered water in the well backs up the drain of the filter-bed. When the sand has been covered by 2 or 3 inches of water, the rest of the depth may be filled in the usual way. It will be evident that if it is wished to run the first of the water, after re-filling a filter, to waste, this can readily be done; also that the filter can, if it is wished, be made to work at a reduced rate for a short time after filling, either by adjusting the spindle so that the valve can fall only a certain distance, or by removing weights placed on the piston and adjusted to normal working.

A valve of the kind described was made at the Engineering College of the Imperial University, Tokio, and tried in connection with the small University waterworks. It was found that if the pressure at the inlet of the valve was suddenly changed, there was, for an instant, a change in the differential pressure at the diaphragm due to the inertia of the valve; but that, however great the change, if made slowly, the differential

pressure, and consequently the discharge, remained constant. This arrangement is being adopted for the Tokio waterworks and for the Osaka waterworks, and the Author trusts it may prove useful in other cases.

The communication is illustrated by a drawing, from which the *Figs.* in the text have been prepared.

(Paper No. 2679.)

"Mining-Operations."

By JOHN ROBERTS.

(Abstract.)

AFTER some introductory observations the Author proceeds to treat, in somewhat general terms, of the machinery required for the development and permanent working of a metalliferous mine; remarking first that, whether operations are undertaken in virgin ground or on an abandoned and subsequently re-opened property, the mechanical appliances required are nearly identical, and should in no case be of an inferior class.

If a mine is to be worked below the adit level, the first considerations will be the best site for the engine-shaft and the most suitable form of pumping-engine. Should there be several adjacent lodes on the property, the shaft must be sunk in such a position as to command the whole group. Water-power, if available, is to be preferred to steam for pumping purposes. The ordinary water-wheel has an advantage over the turbine in respect of its direct action; but where a high fall, approaching 60 feet, is required, the motion is too slow to permit of "forking" (*i.e.*, pumping water from the sump, or bottom of the engine-shaft) being done as quickly as may be required after a stoppage. If the water-wheel be driven at more than about 2 revolutions per minute, a great part of the energy of the water is lost on the wheel; whereas turbines may be geared so as to have two or three different speeds, as required, without consequent loss of any power in the fall of water. Another objection to ordinary water-wheels is their liability to be ice-bound in winter, a mishap which, with the exercise of a little care, does not occur to turbines. If the water-power is generated at a great distance from the shaft, electric transmission may be advantageously adopted. Wind-mills are so uncertain and variable in their action as to be useless for pumping-purposes. Where water-power is not available, steam-power is required.

Combined pumping-and-winding engines should only be adopted

for temporary operations, such as the sinking of shafts; for, if there is not often great loss of power, there must be loss of time, since the speed required for winding and for pumping cannot always be the same. For deep or heavily-watered mines the Cornish pumping-engine cannot be surpassed; but this should not be used in conjunction with the Cornish boiler, which, having no cross-tubes, is not an economical fuel-burner. The Cornish engine has this advantage over rotary engines—that the speed is automatically governed, and no unnecessary stroke is made. In mountainous districts, where the mine is not heavily watered, the Robey semi-portable engine, or a similar kind, is found very convenient for pumping-operations.

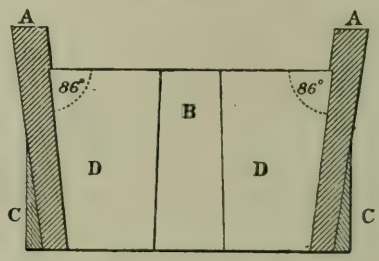
The most suitable pumps for general purposes are the "drawing lift" and the "plunger lift," the former for sinking and for short lifts, the latter for long, or permanent lifts. Ten or twelve fathoms is quite sufficient length for a sinking-lift. Should this length be exceeded, it becomes very unwieldy, and much time is lost in shifting it about, especially if the shaft has an inclined direction.

As regards the form of bucket used in the drawing-lift, when the working-barrel is bored true and there is no gravel in the water, a bucket with steel rings answers well enough, but it is hardly suitable for use during shaft-sinking, as the gravel will soon wear the barrel and render it unfit for use, necessitating re-boring; whereas, with leather gearing, a working-barrel will last for many years. The Author is of opinion that there is no necessity for boring the working-barrel of a drawing-lift, provided the core for the casting is made perfectly true and smooth, as in a few days the surface will wear sufficiently smooth, and the hard "skin" of the casting will be retained. The form of bucket-shell recommended is shown in sectional elevation in *Fig. 1*, and in plan in *Fig. 2*, wherein A is the leather gearing, B the chamber for the prong, C the metal hoop (which should be made of best Low Moor iron), and D the body of the shell, the bevel between the top and side faces of which is an angle of 86°. This slight bevelling of the part D allows the hoop and gearing to be driven tight, without any risk of their working over the top. *Fig. 3* shows the shape assumed by the leather when inserted in the barrel. Whilst the hoop should not be much less in external diameter than the bore of the barrel, it is unnecessary that it should work on the surface of the barrel; hence the hoop need not be turned in a lathe. If the hoop be of too small diameter, the leather A will curl downwards between the surface B of the

working-barrel and the body of the bucket, and the whole will become firmly attached together. Such a mishap could not occur if the form shown in *Fig. 3* were adopted.

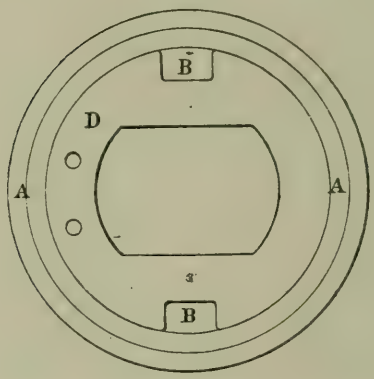
Joints in bucket-rods should be of the clasp variety, the faces of the joint being at the angle shown in *Figs. 4* and *6*. In the case of large pumps, the tongue and chamber should be as shown in *Fig. 6*, that form being stronger than the other.

Fig. 1.



Elevation showing Section of Hoop and Gearing.

Fig. 2.



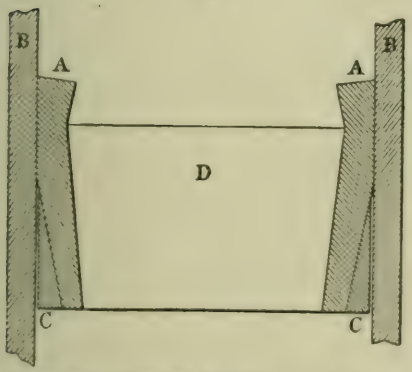
Plan.

In order to steady the rods in the pump, and to prevent them from rubbing against and wearing the sides, small wheels, tired with india-rubber rings, should be attached in the manner shown in *Fig. 5*. One of these wheels is shown in section, to larger scale, in *Fig. 7*, p. 332. The wheels A A should be held in position by two wrought-iron plates B B, one on each side of the rod C, the

plates being clamped to the rod by a bolt at each corner. If a thin sheet of lead be inserted between the surfaces of the plates and the rod, the grip will be perfect. Two pairs of these plates and wheels should be clamped around the rod at right angles to each other. About half-an-inch play should be allowed between the tires of the wheels and the sides of the pump. India-rubber rings make the most convenient joints in the pump column.

A rough-and-ready method of stopping a leaky joint in mine pumps is to cut up a pound or two of hemp-yarn in lengths of 3 or 4 inches, making one, two, or three knots in each single

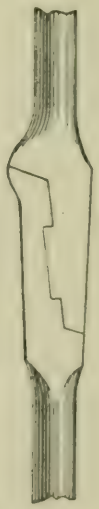
Fig. 3.



Elevation showing Position of Gearing in the Working-Barrel.

A A Gearing. B B Side of Working-Barrel.

Fig. 4.



yarn, beat it into moist clay of the consistency of putty, and free from grit, work the mixture into lumps about the size of tennis-balls, and drop them one by one into the head of the lift or pump. As the bits of knotted yarn are liberated from the clay they rise, and on reaching the leaky joint are forced into it by the pressure of the escaping water, thus stopping the leak completely.

When air exists between the upper and lower clack-pieces of a plunger-lift (a general sketch of which is given in the Paper), considerable difficulty is experienced on starting the pumps; and, before screwing on the door of the lower clack-piece, the

pump-man should be instructed to place one or two lighted candles inside it, in order to exhaust as much air as possible, and so assist in creating a vacuum. An additional precaution recommended is that the packing in the stuffing-box be loosened a little, and that water be thrown into it on the up-stroke.

In the appliances and methods of winding, great improvements have taken place within the last thirty years. Wire ropes have superseded chains. The skip has largely replaced the kibble, which, however, has many advantages. Speaking generally, and

Fig. 5.

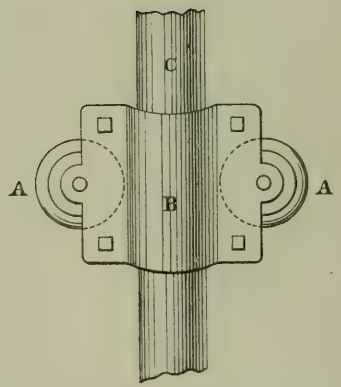
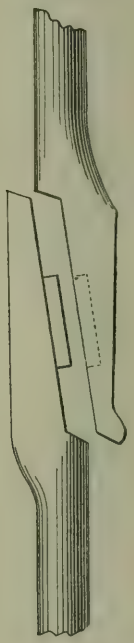


Fig. 6.



from an economical standpoint, skips are preferred to cages in metalliferous mines, the skips being, advisedly, constructed of cast-steel plates.

In underground haulage the wagons or "tubs" should have their fore and hind wheels set as near together as is consistent with steadiness, so that sharp corners may be readily passed. The joints of rails should be fish-plated, and the rails should be properly bent into the required curves. The most suitable section of rail for underground roads is, steel T rail, weighing 14 lbs. per yard, this being easily curved and fish-plated.

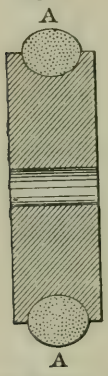
After a brief reference to the ordinary method of filling wagons and skips, the subject of winding is treated, including the Cornish winding-cage, or "whim." Where water is used as motive power, and the supply is limited, electric transmission should be adopted, or else a turbine should be erected with sufficient reservoir capacity at the head of the pipe to store the water when the winding-engine is not in operation. The engine should not be coupled with other machinery and driven simultaneously. If steam-power be used, the engine should have double or triple expansion, as there is necessarily a great loss of power with a single-cylinder engine. The importance of having an abundance of power at command should not be overlooked.

Passing from mining-machinery to underground mining-operations, it is observed that mines are variously situated, some being reached entirely by adit levels, others partly by adits and partly by shafts, and others by shafts only. Speaking generally, the first class have an advantage over the second and third, and the second class over the third; the advantage consisting in the saving of expenditure involved in pumping and winding and other items. In all three cases, however, the actual mining of the ore-deposit is accomplished by similar methods, namely, the driving of "levels," the sinking of "winzes," the putting-up of "rises," and "stoping." The Tchatoura manganese mines, in the Caucasus, afford a quite exceptional case, where the deposit is precisely like a coal seam in respect of its horizontal and regular occurrence. The deposit is reached by driving short adits in the mountain side, and should be worked by the pillar-and-stall system.

The rock met with in mining varies in degree of hardness, from that requiring to be broken by means of explosives, to soft material which must be timbered at every inch or otherwise secured. For tunnelling in hard rock, the power rock-drill should be employed. Where such drills are used, it is sometimes advantageous to adopt the method of volley-blasting; that is, the blasting of a number of holes simultaneously by means of an electric battery or an instantaneous fuse. In this case, a number of holes are drilled in the face of the tunnel, as shown in *Fig. 8*, every hole in the inner ring converging towards the central hole, which is drilled at right angles to the face of the tunnel. When blasted instantaneously, the whole face within the line of holes will be brought out bodily for the distance of the boring, which may be from 3 to 6 feet, according to the hardness and toughness

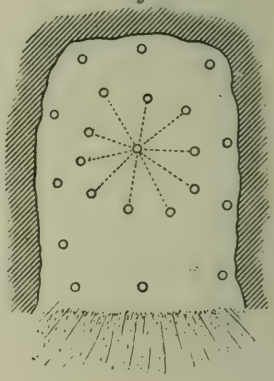
of the rock. It may be found necessary to drill another series of holes near the sides, roof and floor, as also shown in *Fig. 8*, and, after that, a short hole here and there to remove any "archings" between the sides and the face. *Fig. 9* represents another method of attacking the face of a tunnel, in which the holes are fired singly, or two or three at a time, according to circumstances. Assuming that the face of the tunnel or gallery has been trimmed "square," a row of holes is started at a height of about 2 feet above the floor, the holes being drilled at an angle of about 40°, more or less according to the nature of the ground, as in *Fig. 10*, where A B represents the face of the tunnel, and *a*, *b*, *c*, *d*, the angles at which the holes are drilled. Supposing, then, that a set of holes has been drilled, as represented in *Fig. 9*,

Fig. 7.



SECTION OF WHEEL IN FIG. 6.
A A India-rubber Ring.

Fig. 8.



the middle hole *a* in the bottom row will be first dealt with; after which *b* and *c* may be fired simultaneously. If these holes are successful, the end of the tunnel will have been "undercut," and the next row, *d*, *e*, *f*, may then be fired. Men should not be permitted to charge more holes than are to be fired at once; for, with the greatest precautions, mishaps may occur owing to the accidental firing of fuses. Hand-power rock-drills have not given satisfactory results.

In driving along the course of a "flookany" lode (*i.e.*, a lode alongside of which a vein of argillaceous matter runs), the flookan should be worked out as far forward as possible, so as to facilitate the subsequent blasting of the rock. Shafts should be of ample capacity, and sunk in as straight a line as possible, so as to reduce wear and tear to a minimum. A perpendicular shaft is always

the best for permanent work, but cannot always be adopted in preliminary or prospecting-operations. In any case, the shaft should be directed in as straight a line as possible, even if started on the underlie of a lode, the direction being kept as nearly as possible to the main inclination of the lode. For securing the tops of permanent shafts, stone or brickwork is preferred to timber, which requires constant repairing and renewal. When, however, masonwork is used, the shaft must be circular or oval in cross-section, whereas an oblong or a square section is desirable. The ordinary methods of shaft-timbering are then described. As to pit-heads, whatever form be adopted, the height should not be less than 30 feet. A high pit-head lessens the risk of over-winding, and gives great facility for setting ore-screens. The most expeditious method of sinking shafts in rock hard enough for power-drills is that by volley-blasting. In cases where there

Fig. 9.

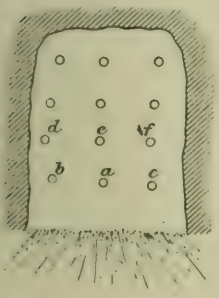
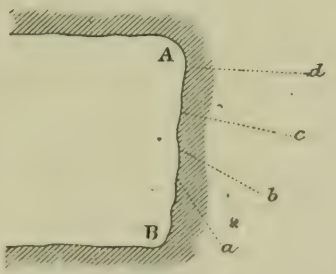


Fig. 10.



is much water to contend with, this mode of firing may not be found so practicable. The ordinary method of sinking in watery ground is then discussed, the Author noting that, when the shaft has been squared down and water covers the bottom, a "sinking-hole" is drilled close by the lift-pump, or a set of holes for a volley-blast is bored; in either case a pit is made, and the "nose" of the pump is lowered into it, the object of the sump-man being to work in as dry ground as possible, and to ensure the efficiency of the shots. The common practice in this country is to sink 10 fathoms, and then to drive off levels or galleries, that distance being considered a convenient one for "stoping" the ore from one level to the next. This, however, depends very much on circumstances. It is frequently the case that ore-deposits are at some considerable distance from the shaft, and that much "dead" ground has to be driven through before the ore is reached;

in which circumstance it would be more economical to sink 15 fathoms before driving a new level. With a heavy pump, it is inconvenient to sink more than this distance before driving, as the pump becomes very cumbersome for shifting about, especially if the shaft is on the underlie of the lode; besides which, the joints are liable to leak by reason of undue strain. In order to avoid shifting about the pump to lower it, some sump-men suspend it on bearers and attach a suction-hose to the bottom; this method, however, obtains no favour with experienced sump-men, who find that the suction-hose occupies too much space: in addition to which there is a great expenditure of time and trouble in detaching and drawing it up for every blast, and in making subsequent re-connection. Others recommend a sliding, or telescopic wind-bore, so as to obviate the necessity for shifting the pump, the wind-bore being operated by a screw or by pulley-blocks. These devices are, however, mere makeshifts to accommodate unskilled workmen, and the Author has never had occasion to adopt them. The shaft having been sunk and levels driven for, say, from 10 to 20 fathoms, and, assuming the ground driven through to be "payable," a small shaft, or "winze," is sunk from the upper to the lower level, or a similar connection—in this case termed a "rise"—is worked upwards from the lower to the upper level. Communications of this kind should be made at every 10 or 15 fathoms along the levels, unless there are strong reasons for assuming that no payable ore exists in the lode between the two levels. It should be noted that, while the ore in both levels may be poor, there may be rich ground between them.

Up to this point the operations described are in the nature of "developments," and no considerable returns can, ordinarily, be expected during their progress. "Development" should keep pace with the rate at which ore is extracted from the mine. It is ruinous policy to obtain large outputs of ore, when development is neglected, or is carried on in a niggardly manner. The Author describes the ordinary systems of extracting the ore, by "underhand" and "overhand" stopes respectively, observing that the system adopted should be determined by the width and hardness of the lode, and the hardness of the containing rock or "country." He would adopt overhand stoping in the following circumstances:—

(1.) When the lode is so narrow that some portion of the containing rock has to be removed in order to make room for working. In this case the required space might be obtained by first removing a certain width of "country" for the whole length of the stope,

and to, say, a height of 5 or 6 feet at each stage, overhand stoping being then proceeded with.

(2.) When the lode is of great width, and its walls will not stand when laid bare. It rarely occurs that the footwall gives any trouble when exposed, but the hanging-wall is often so broken up and decomposed as to render underhand stoping impracticable. In this case the whole of the space made by removing the lode must be filled up as the stoping proceeds, leaving only sufficient room for work to be carried on. Waste may have to be separated from the ore by hand-picking; and, if there is not enough waste to fill up the space, the "deads" produced by driving the levels may be utilized for that purpose. In an operation of this kind the loss of a certain amount of ore is inevitable; but care must be taken so as to keep such loss at a minimum.

(3.) When the lode is only from $1\frac{1}{2}$ feet to $4\frac{1}{2}$ feet wide, or thereabouts, and has firm walls, and can be easily worked with a "pick." In this case overhand stoping is advantageous, because the ore-stuff falls away from the pick to the shoot for filling the wagons, no shovelling being required. In a narrow working of this kind, stages, or platforms for the miners, are easily and quickly constructed. There may, however, be circumstances in which a lode of this description might with advantage be worked by the underhand system.

Speaking generally, the Author is of opinion that, when the ground is hard, and the lode of sufficient width to be worked without removing any of the "country rock," and it can be reached by underhand stoping, that method is to be preferred, for the reason that holes for blasting are far more easily drilled underhand than overhand. All other things being equal, three holes can be drilled underhand whilst two are drilled overhand. The ratio of progress by the two methods would not, however, be as 3 : 2; for, ordinarily, underhand holes will not do the same execution as holes in the roof, especially where the roof is wide. In stoping underhand, however solid the walls may appear to be, a floor, or "stull," should be put in overhead at intervals of, say, 30 feet, and *débris* stacked upon it, so as to prevent accident through the falling in of any part of the hanging-wall. Should the hanging-wall appear likely to collapse unless supported, an arch of unworked ground should be left here and there along the stope.

As to choice of timber for supports in permanent ways, the Author remarks that, in a dry place, oak will not be serviceable for more than four or five years, as it is soon seized by "dry rot";

in water, however, it will stand well for an indefinite period. Spruce is useful for short props outside permanent ways, for temporary coverings, and for tramway sleepers; sleepers of spruce are less liable than those of oak to be split in driving spikes. Scotch fir lasts considerably longer than spruce in water. Woods of fine fibre, such as sycamore, beech, birch, &c., are to be avoided, except for temporary purposes. Of foreign timbers, Norwegian fir is, perhaps, for cheapness and durability as serviceable as any. Pitch pine is durable, and is capable of supporting great weight, and it is recommended for securing shafts, especially for the framework for the "collar," where the timber is required to be square. But for permanent props, "stull-pieces," and underground timbering in general, larch cannot be surpassed, if cut in the proper season of the year. This wood has during recent years come into considerable favour, and its price has consequently risen.

The Paper concludes with some remarks on the approximate valuation of mineral veins, or lodes, observing that, if the vein contains no admixture of gangue, the number of tons per fathom may be readily calculated on the basis of the specific gravity of the mineral which it contains. When, however, there is an admixture of other substances, the proportion which the mineral bears to the rest of the lode-matter has to be considered. In the former case, the Author lays it down as an axiom that, "*at 1 foot wide, the number of tons of mineral in a lode per fathom*[1] *is equal to the specific gravity of the mineral.*" For example: let the specific gravity of lead ore (galena) be taken as 7·58. A lode of such mineral, 1 foot wide, will produce nearly 7 tons 10 cwts. to the fathom. Again, a lode 1 foot wide of yellow copper ore, the specific gravity of which may be assumed at 4·3, will produce 4 tons 6 cwts. to the fathom. In the case of lead ore, of specific gravity 7·58, assume that the lode is 5 feet wide, and that only one-tenth by volume is lead ore, the remainder being valueless gangue. Then the width of the lode may, for valuation purposes, be considered to be 5 feet ÷ 10, or 6 inches; and its value per fathom will be 7 tons 11 cwts. ÷ 2, or 3 tons 15 cwts. 2 qrs., which, multiplied by the current price of lead ore, will give the money value of the lode per fathom.

Copper ore is never dressed to so high a standard as lead ore; hence the specific gravity of the marketable product seldom

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[1] The expression "per fathom" in these calculations signifies per fathom in longitudinal distance and in height; in other words, per square fathom. The variable quantity is the width of the lode.

approaches that of pure copper ore, but varies according to the specific gravity of the foreign matter contained in the lode-stuff, and the standard to which it is dressed. In any case the percentage of fine copper must be taken into consideration. Take, for example, the same width of lode as in the previous case, viz., 5 feet. Assume that dressing reduces the volume by one-half, and that the dressed ore contains 10 per cent. of fine copper. If the gangue be quartz, or a mixture of earthy matters, the specific gravity will not exceed 3·2 per foot of width, which would give 3 tons 4 cwts. to the fathom. The net width of the lode may, for valuation purposes, be taken at 5 feet ÷ 2, or 2½ feet; hence the weight of ore per fathom is 3 tons 4 cwts. × 2½, or 8 tons. Since the dressed ore contains 10 per cent. of fine copper, its money value will be 10 × current price per unit. If, however, the valueless gangue in this lode be a metallic substance, the specific gravity will probably be 4, and the weight per fathom 10 tons. If the gangue be fluorspar, the specific gravity will be 3·5, and the weight per fathom 8 tons 15 cwts.

The value of a lode of zinc blende may be determined in the same way as that of a lead-ore deposit, since the ores are concentrated in much the same manner, and dressed to as high a standard as possible. A practised eye may estimate the approximate percentage of blende in the lode-stuff, but an accurate determination of the value of the lode can only be arrived at by reducing a large sample of, say, 20 to 30 tons. Suppose that such a test produces 20 per cent. of blende, and that the width of the lode is 6 feet. Then, since 20 per cent. is equivalent to one-fifth of the whole bulk of the lode, the width of the lode may be taken as 6 feet ÷ 5, or 1·2 feet. Assuming the matrix to be an earthy substance, the calculation becomes 1·2 feet × specific gravity, 3 = 3·6 tons, or 3 tons 12 cwts. per fathom.

To estimate the value of a lode of tin ore, a fair sample of the lode-matter must be assayed. Suppose that an assay of a properly-selected sample gives a return of 1 cwt. 1 qr. 7 lbs. of black tin per ton, also that the width of the lode is 6 feet, and its specific gravity 3. Then, the number of tons of lode-matter per fathom will be, for the whole width, 6 × 3, or 18 tons. Hence the amount of black tin in the lode per fathom will be 1 cwt. 1 qr. 7 lbs. × 18, or 19 cwts. 2 qrs. 14 lbs., the value of which, at £54 per ton, is £48 5*s.* 3*d.*

Gold, occurring in reefs or in alluvial deposits, is estimated in ozs. dwts. and grs. per ton of ore. Suppose a reef be 3 feet wide, and a fair sample assays 1 oz. 10 dwts. per ton. The specific

gravity of a quartz-reef being assumed at 2·6, the weight per fathom of such reef-stuff 1 foot in width will be 2·6 tons, or 2 tons 12 cwts. Hence a reef 3 feet wide will weigh 2 tons 12 cwts. × 3, or 7 tons 16 cwts. per fathom; and the value in gold per fathom of reef will be 7 tons 16 cwts. × 1 oz. 10 dwts., or 11 ozs. 14 dwts.

Silver, when it occurs in galena (the ordinary ore of lead) is estimated in ounces per ton of dressed lead ore, and its value added to the price of that article. When it occurs in other substances the result of the assay is stated in ounces per ton of ore; and the value of a silver lode may be arrived at in the same manner as that of an auriferous deposit.

In making calculations such as the foregoing, allowances must be made for any cavities and crevices that may occur in the lodes. In the examples herein given, the Author has assumed that there are no such occurrences, and that the lode is homogeneous throughout. A soft lode will necessarily yield a smaller weight of lode-stuff than a hard lode, and there may be a difference of as much as 25 per cent. in the weight of two lodes of the same width, owing to difference of hardness of contents. Hence the difficulty of laying down absolute rules.

The Paper is accompanied by 10 drawings, from which the *Figs.* in the text have been engraved.

OBITUARY.

ERNEST WERNER VON SIEMENS was born on the 13th of December, 1816, at Lenthe, a small village near Hanover, where his father, Christian Ferdinand Siemens, rented the manor farm. Shortly after the birth of his brother, the late Sir William Siemens,[1] the family removed to Mecklenburg-Strelitz and remained at Menzendorf until the death of the parents. Werner was at first educated at home by private tutors and then at the Gymnasium at Lübeck. As he did not find classical studies to his taste he decided to become an architect. On making inquiry it was found that the course of study at the "Bau-Akademie" of Berlin would be too expensive, so he applied for leave to join the Prussian Royal Engineers. There were, however, too many candidates for this corps; but he was permitted to join the Royal Artillery and obtained in this way the same technical training as that given at the Bau-Akademie. After studying for three years at the Artillery and Engineers College at Berlin, he obtained a commission and was stationed at Magdeburg, where he was joined by William.

During his leisure hours Werner carried out scientific experiments with the greatest zeal; in fact he once nearly lost his hand through a premature explosion of chemicals, when he was attempting to reproduce friction-fuses, an invention of a cousin, Lieutenant Adolph Siemens, of Hanover, by which the old method of firing cannon has been superseded. In the autumn of 1840 Werner became acquainted with Jacobi's invention for depositing copper by means of electricity and at once tried to obtain deposits of other metals in a similar manner. He had an unexpected opportunity of following up his experimental researches at leisure, as he was condemned to five years' confinement in a fortress for having acted as second in a duel. In the small laboratory which he was allowed to establish in his cell, he succeeded in depositing gold and silver by employing the same solution which he and his brother-in-law, Professor Himly, of the University of Göttingen,

[1] Minutes of Proceedings Inst. C.E., vol. lxxvii., p. 352.

had used when they repeated Daguerre's experiments for producing portraits by the action of light. Most unexpectedly he was granted a free pardon after a short imprisonment, and brought much disgrace upon himself by petitioning to be allowed to remain a little longer in order to finish his experiments.

Werner was now ordered to join the pyrotechnic department at Spandau. Owing to his knowledge of chemistry he succeeded in producing some novel colour effects on the occasion of a special display of fireworks at Glienicke before Prince Karl. Shortly afterwards he was ordered to join the Artillery workshops and was thus enabled to continue his physical studies and to enlarge his technical knowledge.

In 1843 William Siemens succeeded in selling Werner's English patent for electro-gilding to Messrs. Elkington of Birmingham. Werner then made some further inventions which William tried to introduce into England, but a visit to this country and subsequently to Paris convinced Werner that they were simply wasting their time by endeavouring to introduce inventions without adequate means at their disposal. He therefore dropped all the technical connections he had made in order to develop his inventions, and resumed with redoubled vigour his scientific studies. In the year 1845 he published in "Poggendorf's Annalen" a description of an application of electricity to measure the velocity of projectiles at any stage of their flight by marks produced by electric sparks on a rapidly revolving cylinder of polished steel. About the same time the General Staff was considering the question of replacing optical signalling by electrical telegraphy, and Werner succeeded in making an important improvement in Wheatstone's alphabetical instrument. This improved apparatus was manufactured by Mr. Halske, whose acquaintance he had made at the meetings of the Physical Society of Berlin.

Owing to an incautious participation in a political demonstration, Werner was ordered to leave Berlin and rejoin his regiment. In searching for means to bring about the countermanding of this order, he thought of Professor Schoenbein's invention of gun-cotton, which, however, had not yet been produced in a satisfactory manner. On hastily making some experiments in the laboratory of Professor Erdmann, Werner tried to improve the action of the nitric acid by the addition of sulphuric acid, and greatly to his joy succeeded in producing a very much better material than Schoenbein. He at once brought this to the notice of the authorities, and was sent to the powder factories at Spandau in order to examine fully into the qualities of his gun-cotton. After

he had reported that it was more suitable for mining purposes than for artillery, Professor Otto, of Brunswick, published a description of the same improved method of making gun-cotton, which he had discovered independently.

Shortly afterwards Werner joined the Telegraph Commission of the General Staff, and made experiments in the summer of 1846 with gutta-percha as an insulating material for underground wires. He constructed a special machine for pressing gutta-percha round the conductor, the principle of which is in use in most cable works at the present day. Declining to take advantage of his position in the Telegraph Commission which led him to aspire to become official director of the State Telegraphs, he determined to leave the service as soon as the Commission had definitely settled the organization of the telegraphs.

As a preparatory step, before carrying out this intention, he entered into partnership with Mr. Halske, and they commenced operations on the 12th of October, 1847, by founding the firm of Siemens and Halske, of Berlin. From this small beginning the firm developed rapidly, so that it soon became necessary to establish branches in St. Petersburg, Vienna and London.

The revolution of March, 1848, put an end to the Telegraph Commission, and Werner was sent to Kiel to carry out some proposals he had made for defending the harbour by submarine mines. A complete system of mines was submerged under his direction, and trials with small charges and boats proved that the system worked perfectly, but the Danes never approached near enough for the large mines to be fired during the war. When taken up afterwards they were in perfect order. This was the first time that submarine mines had been used.

On returning from Schleswig-Holstein he found his partner actively engaged in preparing to establish underground communication between the principal towns of Prussia. His proposal to have the gutta-percha wires further protected by iron or earthenware pipes was rejected by the Telegraph Department on account of the extra expense, and the wires were simply buried in the ground. An exception was made where the wires had to cross rivers, and the cable across the Rhine at Cologne is the first instance of the immersion in water of an armoured cable insulated with gutta-percha. As the length of these lines increased, the phenomena of capacity and self-induction interfered with the proper working of the instruments and induced Werner to study carefully the laws governing these disturbances and also the means for determining the position of faults in the insulation.

The result of these labours was described in his "Mémoire sur la télégraphie électrique" presented to the Academy of Sciences in Paris in the year 1850.

In June, 1849, Werner resigned his commission, and in 1852 he married Fräulein Mathilde Drumann, the daughter of a professor in Koenigsberg. In the same year he went for the first time to St. Petersburg and succeeded in obtaining from the Russian Government an order to construct telegraph lines. As these orders increased in importance, his brother, Carl, proceeded to St. Petersburg in 1853 and carried out in the following years the extension of telegraphs, which soon connected all the principal towns of the empire. In 1857 Werner was present at the submersion of the cable between Bona, in Algiers, and Cagliari, in Sardinia, and developed the theory that, in laying submarine cables, the cable should be held back by a brake equal to the weight of a length of such cable, reaching vertically from the ship to the bottom of the sea. For some years he had continued to study the capacity and self-induction of cables, and in 1859, when present at the laying of the Red Sea cable, he succeeded in improving the methods of signalling through long submarine cables by employing a condenser, using for this purpose a piece of submerged cable. During the laying of this cable systematic tests were introduced by him, and by means of his mercury unit of electrical resistance he was enabled to make accurate measurements for determining the position of faults. Returning from Aden in the P. and O. steamer "Alma," Werner and his companions were wrecked near the Harnish Islands in the Red Sea and had a very narrow escape from drowning.

In 1860 the London firm was appointed official tester of submarine cables supplied to the British Government, and in that year William Siemens read before the British Association a Paper on "Submarine Electric Telegraphs," which embodied a report made by Werner and William to the Government, and set forth all the principles underlying modern methods of cable-testing. In addition to this work Werner devoted much attention to the development of telegraphic and measuring instruments for scientific and technical purposes. In the period between 1850 and 1860 he produced, with Halske, improved Morse instruments, automatic type-writers working with perforated strips of paper, railway gong-signals, magneto-inductors with the well-known Siemens armature, polarized relays, induction-writers, an induction machine for the production of continuous currents, a method for duplexing land-lines, and a Paper on Electrostatic Induction

(Poggendorf, 1857), in which an apparatus is described for producing ozone.

In 1859 Werner was elected to the Chamber of Commerce of Berlin, and in the following year he received the honorary degree of Doctor of Philosophy, on the occasion of the celebration of the jubilee of the Berlin University. In 1864 he was elected a member of the Prussian Parliament for the Solingen-Remscheid district and joined the progressist party (*Fortschrittpartei*) which opposed the Government in the memorable conflict preceding the war with Austria. After resigning his seat three years later, he organized, with the help of his brothers William and Carl, the Indo-European Telegraph Company, for which the united firms built special lines through Russia into Persia, connecting their line at Teheran with the telegraph lines of the Government of India, while the Prussian Government and the English Telegraph Company completed the connection from the Russian frontier to London. In the meantime Carl Siemens had acquired for Werner and himself a copper mine at Kedabeg, in the Caucasus, which after considerable trouble was ultimately developed into a very remunerative investment.

In December, 1866, Werner showed to some of the physicists in Berlin—Magnus, Dove, Riess, and Du Bois Reymond—his dynamo-electrical exploders, and described on the 17th of January, 1867, the dynamo-electric principle to the Berlin Academy of Science. He also invented at this time an alcoholometer, an instrument registering automatically the quantity of liquid passing through it and its equivalent in proof spirit. The development of the business induced the brothers, on the retirement of Mr. Halske in 1868, to make the firms in London and St. Petersburg independent of the Berlin house, the London firm changing its name at the same time to Siemens Brothers. Werner then began to leave the actual management of the concern to his well-trained staff of assistants, taking up himself the more scientific questions arising from the business.

In 1869 he married a second time, having lost his first wife in 1865. In 1874 he was elected a member of the Berlin Academy of Science, to which he subsequently contributed many Papers on various subjects. From 1863 he had agitated for a reform in the patent laws, and at last, in 1876, a meeting was arranged between the leading industrial authorities, counsel, and judges from all parts of Germany, who drafted a Patent Bill, based on Werner's original proposals, which has since with a few modifications become law.

Of the many contributions made by Werner to technical litera-

ture, two may be specially mentioned; the first a Paper on "Electricity in the Service of Mankind," read in 1879, and the second a Paper on "The Natural History Period," published in 1886. In the latter Paper he explained the necessity of continually extending experimental researches in physical science and carried out this theory by presenting the German empire with a site on which the Physical Technical College has since been erected. In 1889 he published a most valuable and interesting account of his scientific and technical work.[1]

Among the marks of recognition he received, the patent of nobility bestowed upon him by the Emperor Frederick should be specially mentioned. He valued also greatly his election as an Honorary Member of the Institution on the 1st of March, 1892.

A few days before his death, which occurred on the 6th of December, 1892, Werner received from the printer the first copies of his Autobiography, from which the foregoing facts have been collected.

JOSEPH NAPOLEON DU BARRY[2] was born at Bordentown, New Jersey, on the 19th of November, 1830. His father was Mr. Edmund L. Du Barry, a surgeon in the United States Navy, and his mother, who survives him, was the daughter of Mr. William Duane, editor of the Philadelphia *Aurora*. After attending schools in his neighbourhood, young Du Barry was sent to Washington, where he received a classical education. In June, 1847, when only seventeen years of age, he entered the service of the Pennsylvania Railroad, being employed in the engineering department as a rodman. For three years he was engaged on the preliminary surveys and location of the line between Altoona and Pittsburgh, the most mountainous section on the whole road. The difficulties of construction over the main ridge of the Alleghany Mountains were great, and these three years spent in the then mountain wilderness of Western Pennsylvania served as an invaluable school for the young man and developed not only the skill but the strength of purpose and fertility of resource, which made him capable of assuming and faithfully discharging the responsibilities which were afterwards placed upon him. In 1850

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[1] "Wissenschaftliche und technische Arbeiten, von Werner Siemens." Berlin, 1889.

[2] This notice is taken, with some slight alterations, from the *Railroad Gazette* of New York, 23 December, 1892. In the Library of the Institution is a copy of a memoir subsequently printed for private circulation.

Mr. Du Barry was made Assistant Engineer of Construction. From May, 1852, to May, 1853, he was Principal Assistant Engineer of the Sunbury Division of the Sunbury and Erie Railroad, having charge of surveys and of the location of new lines. From May, 1853, to the spring of 1856, he was Principal Assistant Engineer of the North Pennsylvania Railroad, during its location and construction, and then for a short time Assistant Engineer on the works of the Sand Patch tunnel on the Pittsburgh and Connellsville line.

In May, 1856, Mr. Du Barry was appointed Principal Assistant Engineer of the South Western Branch of the Pacific Railroad of Missouri, which position he held until September, 1858, when he again returned to the service of the Pennsylvania Company as Superintendent and Engineer of the Western Division of the Pittsburgh, Fort Wayne and Chicago branch, which was constructed through to Chicago under his direction. Upon the completion of this work Mr. Du Barry was made Superintendent of the Western Division, extending from Crestline to Chicago, 280 miles. He held this position until December, 1861, when he was appointed General Superintendent of the Northern Central line, which responsible post he filled with great credit to himself and to the company during the exciting period of the War of the Rebellion. At that time the Northern Central was a main artery through which troops and provisions were transported to the Union Army in the South. To prevent the road falling into the hands of the Confederate Army under General Lee, in its march into Pennsylvania in the Gettysburg campaign, which would have given Lee an opening towards Harrisburgh and Philadelphia, all the bridges on the York Division, some twenty in number, including the long Columbia Bridge, were destroyed, and upon Mr. Du Barry devolved the important work of their reconstruction. After the battle of Gettysburg, he was one of the first to respond to the cry for assistance for the thousands of wounded soldiers on the field. Fitting up a relief train, he started with it from Baltimore for the scene. Innumerable difficulties confronted him on this errand of mercy, but all were overcome, and when he returned to that city he carried hundreds of the wounded with him.

In July, 1867, Mr. Du Barry was elected Vice-President of the Northern Central, and Baltimore and Potomac Roads, and removed from Harrisburg to Baltimore. While occupying this responsible position he had under his supervision the construction of the Baltimore and Potomac tunnel under the City of Baltimore, a difficult and costly piece of work. In February, 1875, he was elected Assistant to the President of the Pennsylvania Railroad, his duties

being to assist the President in all engineering questions pertaining to the construction or improvement of any of the properties owned or operated by the company. In October, 1882, Mr. Du Barry was promoted to the position of Third Vice-President, having general supervision of all construction work. He also had charge of the promotion and construction of all new lines in which the Pennsylvania was interested. During his service as Assistant to the President and as Third Vice-President, Mr. Du Barry directed the construction and reconstruction of many railroads. The revision of the line and grades of the Western Pennsylvania Road occupied his attention for several years. One of the longest lines, and perhaps the most important, constructed under his direction, was the Pennsylvania Schuylkill Valley Road, completed in 1885. This Road extends from Philadelphia up the Valley of the Schuylkill River to the top of Broad Mountain, beyond Pottsville, Pa., a distance of over 100 miles, and now forms a division of the Pennsylvania system. He also built the Germantown and Chestnut Hill Road and the Trenton Cut-off.

On the resignation of Mr. Edmund Smith as First Vice-President of the Pennsylvania in June, 1888, Mr. Frank Thomson was appointed to fill the vacancy, and Mr. Du Barry was elected Second Vice-President. In this capacity he had under his direction the treasury and insurance departments, with general supervision of all the financial matters of the numerous corporations in which the Company has a pecuniary interest. He also had charge of all construction work.

Mr. Du Barry died suddenly at his home in Philadelphia on the 17th of December, 1892, the cause of death being attributed to valvular disease of the heart. As a practical railroad man he had few equals. As a private individual he was held in high esteem, his nature being such as to make him a favourite among a large circle of friends. He possessed a strong and distinctive personality, a genial and pleasant temperament, and a rugged honesty, traits which were apparent throughout his life, at his office and in his home.

Mr. Du Barry was a Member of the American Society of Civil Engineers, and was elected a Member of this Institution on the 1st of March, 1892.

JOHN WILLIAM GROVER, born in 1836, was the only son of the late Rev. Henry Montague Grover, of Boveney Court, Burnham, Bucks, for thirty-three years rector of Hitcham in that county. After being educated at Marlborough College and in Germany, he was articled to the late Sir Charles Fox, then a member of the firm of Fox, Henderson and Co., and during his pupilage was engaged not only in the works at Birmingham, but also on the construction of Rochester Bridge and of the Wiesbaden and Eltville Railway, and in superintending the fixing of the tank on the top of the northern water-tower at the Crystal Palace, Sydenham. He was then employed in the office of Mr. (now Sir John) Fowler, Past-President Inst. C.E., for whom he subsequently made preliminary surveys for railways in Portugal and Spain.

On returning to England, Mr. Grover obtained, at the recommendation of Mr. Fowler, an appointment as draughtsman in the office of works of the Science and Art Department, under the late Captain Francis Fowke, R.E.,[1] and soon became head of the engineering and constructive department and chief draughtsman and clerk of the works. He superintended for Captain Fowke, the erection of the North and South Courts at the South Kensington Museum and of the Conservatory of the Royal Horticultural Society, then said to be the lightest piece of ironwork extant. He also conducted a series of experiments on iron-floors and arch-ribs in wrought-iron; prepared reports on various buildings, including that for the Paris Exhibition, and superintended the original design and working drawings for the Exhibition of 1862; but, except as regards the domes, had nothing to do with the plans which were ultimately accepted. At the request of the Secretary to the Committee of Council on Education, he wrote a short pamphlet on the "Education of the Working Classes," for which the Committee awarded him a handsome present.

On the 1st of January, 1862, Mr. Grover, then twenty-six years of age, began to practise on his own account as a Civil Engineer in Westminster. Among the first works upon which he was engaged as Engineer were the construction of 27 miles of the Manchester and Milford Railway, and of the Hemel Hempstead branch of the Midland Railway. In the year 1864 he was appointed arbitrator between the Manchester and Milford Railway Company and its contractor, the sum in dispute being over £25,000, and his award was made a rule of Court. He also

[1] Minutes of Proceedings Inst. C.E., vol. xxx. p. 468.

assisted the late Major-General Scott[1] (then Colonel Scott), in designing and in superintending the erection of the new lecture theatre at the South Kensington Museum, and subsequently of the Royal Albert Hall. In 1868, in conjunction with the late Mr. R. J. Ward, he designed and carried out a wrought-iron pier at Clevedon on the Bristol Channel, an account of which he presented to the Institution three years later.[2] He was also engaged on the surveys of various railways in England and on the Continent, and prepared designs for the works of the Mexican Railway. He acted for various railway companies in Wales, carried out the Westerham Valley branch of the South Eastern Railway, and designed the Kingsland iron bridge of 200 feet span over the Severn, which bridge presents some novel features of construction. In 1873 Mr. Grover went to Venezuela and laid out the difficult mountain line from La Guaira to Caracas[3]; he also made hydrographical surveys of the coast of that country which led to the construction of the harbour of La Guaira and the lighthouse of Los Roques.

On returning to England Mr. Grover abandoned railway work and devoted himself mainly to the question of water-supply, which at that time had become very prominent. Among the principal towns for which he designed and carried out water-works during the next twenty years are Bridgend in Glamorganshire; Westerham in Kent; Newbury and Speenhamland in Berkshire; Wokingham, Bracknell, and adjacent parishes in Berkshire; Leatherhead, Cobham, Ashstead and district in Surrey; and Rickmansworth and the Uxbridge Valley, an extensive district comprising ten parishes in Herts, Middlesex, and Bucks. Some of these he described in a Paper, read before the Institution in 1887, entitled "Chalk-Water Springs in the London Basin," illustrated by the Newbury, Wokingham, Leatherhead, and Rickmansworth Waterworks,[4] which, with three other Papers dealt with at the same time, gave rise to an interesting discussion on water-supply from wells. Mr. Grover was an authority on the question of the present and future water-supply of the Metropolis, upon which he was frequently consulted. He visited the West Indies to report on the surveys for an extensive water-supply, and was also employed on similar works in Egypt, Austria, Denmark, Italy and Switzerland.

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[1] Minutes of Proceedings Inst. C.E., vol. lxxv. p. 319.
[2] *Ibid*, vol. xxxii. p. 130.
[3] *Ibid*, vol. cx. p. 299.
[4] *Ibid*, vol. xc. p. 1.

Mr. Grover died on the 23rd of August, 1892, after a long and painful illness, at the comparatively early age of fifty-six. He was an excellent draughtsman, gifted with a faculty for graphic pictorial effect. As a Fellow of the Society of Antiquaries and a Vice-President of the British Archæological Association, he found scope for the instincts of an ardent antiquary, his exertions in 1886 leading to the recovery and restoration of the well-known Clapham marbles in St. Paul's church in that parish. Amongst his writings may be mentioned "Iron and Timber Railway Superstructures;" "Estimates and Diagrams of Railway Bridges, Culverts and Station Buildings;" "Old Clapham;" and pamphlets on "Flexible Rolling-Stock;" "Suez Canals from the Most Ancient Times to the Present;" and "Ancient Reclamations in the English Fenlands." He was interested in several patents for machinery for various purposes, his spring-washers, by which the constant tightening-up of permanent-way fish-bolts was rendered unnecessary, being extensively used on railways in all parts of the world.

Mr. Grover was elected a Member of the Institution on the 5th of February, 1867, and, besides presenting the two Papers above referred to, frequently attended the meetings and took part in discussions on water-supply and on railways.

GEORGE HIGGIN, son of the late Mr. Thomas Houseman Higgin, who was Mayor of Lancaster in 1835 and afterwards general manager of the Ballymena and Belfast Railway, was born on the 16th of January, 1833. He was educated at Lancaster by private tutors until 1845, when he went to the Grammar School at Preston. At nineteen years of age he entered as an articled pupil the office of the late Sir Charles (then Mr.) Lanyon,[1] and at once showed so much aptitude and resource as to be entrusted with important works in advance of his years. He took part in the survey and construction of the railway from Ballymena to Portrush, and shortly afterwards was entrusted by Mr. Lanyon as Resident Engineer with the responsibility of the survey and construction of nearly the whole of the branch line to Cookstown, which included two important viaducts—one over the river Main at Randalstown, and one over the lower Bann at Loorne Bridge—carried out under a contract with the late Mr. William Dargan.

[1] Minutes of Proceedings Inst. C.E., vol. xcviii. p. 391.

On the completion of these works Mr. Higgin proceeded to Brazil in 1855, and for two years acted as principal Resident Engineer on the Mangaratiba Serra Road, under the late Mr. E. B. Webb.[1] This was a macadamised carriage-road over the Serra, in the province of Rio de Janeiro, constructed for the purpose of bringing down to the Port of Mangaratiba the coffee and other products of the interior.[2] He was next for two years District Engineer on the Bahia and São Francisco Railway under the late Mr. C. B. Vignoles,[3] Past-President Inst. C.E. Unfortunately he contracted yellow fever, and subsequently a severe attack of congestion of the liver compelled him to return invalided to England in 1860.

In the following year Mr. Higgin, having recovered his health, went to Spain with the object of making a complete Ordnance survey of the Peninsula for the Spanish Government. Shortly after commencing the preliminary steps, however, small-pox broke out amongst his staff, and, other difficulties arising with the Spanish Government, the survey was eventually abandoned. Having acquired a thorough knowledge of the language and become acquainted with many influential people in Spain, Mr. Higgin, thinking that the prospects of engineering in that country were promising, decided to settle in Madrid in 1862. From that date to the year 1870 he was occupied in carrying out irrigation-canals, land-reclamations, tramways and hydraulic works, and, having acquired the reputation of an authority on engineering matters in Spain, was largely consulted as to schemes projected in that country. Among the more important canals he reported on are those of Orbigo, Del Ter, Riegos de Ampurdan, Merida, Seville, Talavera, Valladolid, Jarama, Tagus, and Logroño.

In 1864 Mr. Higgin was associated with the late Mr. J. F. La Trobe Bateman[4] as Joint Engineer of the Henares and Esla Canals, the construction of which he described in a Paper[5] presented four years later to the Institution. For that Paper, which was entitled "Irrigation in Spain," the Council awarded him a Telford Medal and a Telford Premium of books. Mr. Higgin also made plans and applied for a concession for a system of tramways throughout Madrid, with extensions to Carabanchel and Navalcarnero, small suburbs of that city. His scheme was approved by the Government authorities, but in those days tramways did not

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[1] Minutes of Proceedings Inst. C.E., vol. lvii. p. 311.
[2] *Ibid*, vol. xix. p. 240.
[3] *Ibid*, vol. xliii. p. 306.
[4] *Ibid*, vol. xcvii. p. 392.
[5] *Ibid*, vol. xxvii. p. 483.

meet with any support in Spain, and as no capitalist would take the matter up it was abandoned. The present system of tramways in Madrid has been carried out by various companies on almost exactly the same lines as he proposed.

Among the more important reclamation works in which Mr. Higgin was interested were those of the Rosas Marshes, Laguna de la Jana, Seville Marshes, Cuadros de Castellon, Albufera de Alcudia, San Carlos de la Rapita, Almenara Marshes, and the Torre Blanca Marshes. The three last were carried out. He also reported on behalf of English firms on the cultivation of madder, esparto, and various other fibrous plants indigenous to Spain. Early in 1871 he went to Monte Video for Messrs. Waring Brothers, to conduct important negotiations with the Government of that country in connection with the Central Uruguay Railway.

In 1872 Mr. Higgin, who had acquired considerable experience of mining in the Peninsula, was selected by Mr. Edward Woods, Past-President Inst. C.E., to act as Consulting Engineer in Spain, on the works of the Bilbao Iron Ore Company, which had been formed for the purpose of constructing a railway and port for the carriage and shipment of the produce of the extensive mines in the rich iron ore districts of Somorrostro and Galdames. These works were fully described in a Paper[1] presented to the Institution in 1877 by Mr. F. C. Barron, the Resident Engineer.

In 1875 Mr. Higgin proceeded to Buenos Ayres as Mr. Bateman's representative on the improvement works of that city. The original engagement was that he should remain there one year to carry out certain negotiations and to report on the state of the works. It resulted, however, in his remaining as Chief Engineer until 1878, during which time great progress was made. While in Buenos Ayres he turned his attention to water-supply, and made several analyses of well-water, rain-water in tanks, and water taken from various parts of the River Plate and its confluents. This led to some interesting experiments on the filtration of water, from which he was able to elucidate the true head of water on a filter, and the almost impossibility of preserving a uniform speed in filtration. These experiments were subsequently presented to the Institution in the form of a Paper,[2] for which he received a second Telford Premium.

During the years 1878 and 1879 Mr. Higgin was engaged in connection with the Riachuelo Docks, Bilbao Docks, River Plate

[1] Minutes of Proceedings Inst. C.E., vol. li. p. 237.
[2] *Ibid*, vol. lvii. p. 272.

Lighthouse, Rosario Pier, and other minor works. In 1881 and 1882 he was occupied in preparing plans and in obtaining from the municipality the necessary concession for the Seville Waterworks, and he ultimately negotiated and obtained the concession upon which the works were subsequently carried out by Messrs. Easton and Anderson. He embodied the information thus obtained in a Paper,[1] which appeared in the Proceedings of the Institution in 1884. While in Seville he prepared plans, and subsequently obtained a concession for the lines constructed by the present tramway company of that city.

In November, 1884, Mr. Higgin commenced a complete survey of the line now known as the Great Southern of Spain Railway, from Murcia to Granada, with a branch to Aguilas, comprising in all a distance of 217 miles. He subsequently became Engineer-in-Chief to this company, which post he occupied until the end of 1891. In 1887 Mr. Higgin was appointed Engineer-in-Chief of the Manila Railway, a line in the Island of Luzon, one of the Philippine group, running from Manila to Dagupan, a distance of 120 miles.

The severe epidemic of cholera in Spain during the years 1884–5 caused Mr. Higgin to again turn his attention to the system of water-supply in various parts of that country, and to make an exhaustive inquiry into the causes of the spread of the epidemic, consequent on water-supplies drawn from rivers. The results of this inquiry were given in an article which appeared in *Nature*.[2] His services were subsequently retained by the London County Council in connection with an inquiry into municipal water-supply with regard to the pollution of the River Thames. In the early part of 1891 Mr. Higgin proceeded to Manila on behalf of the Manila Railway Company, for the purpose of making an inspection of the line. On his return journey in June of the same year, he took a slight chill at Hong Kong, and at Salt Lake City was seriously ill. On arriving in England he was found to be suffering from Bright's disease, which was attributed to the chill. For a time his health seemed to improve and he was able to attend regularly to business; in December, however, he again took a chill, which resulted in an attack of what was at first supposed to be facial paralysis, but was subsequently found to be a more serious matter. He was advised to go away and entirely give up business, at any rate for six or eight months, so that he

[1] Minutes of Proceedings Inst. C.E., vol. lxxviii. p. 334.

[2] *Nature*, vol. xxxiv. p. 149.

might have complete rest. He could not, however, be induced to give up the direction of the various undertakings he had in hand, and there is no doubt that this in a great measure hastened the end. In the following August he went to Guernsey, to make arrangements for wintering there, and hoping to benefit by the trip. Unfortunately, however, the journey overtasked his physical powers; shortly after his return he had a serious stroke of paralysis which proved fatal on the 8th of November, 1892.

Only those intimately connected with Mr. Higgin were aware of his indefatigable activity and of how little he spared himself when duty called. In making plans or in general designing he was most particular down to the smallest detail, to which he always gave personal supervision. His leisure was devoted to literature, his most important works being:—"Spain in 1866"; "Arthur Middleton—A biography," published by Trübner; "Padilla and Other Poems," printed for private circulation; "A Working-man's Philosophy," published by Chapman and Hall; and "Commercial and Industrial Spain," published in 1886 by Effingham Wilson. Ever ready to assist those in adversity, by his tact and kindness of heart, he made himself universally popular.

Mr. Higgin was elected a Member of the Institution on the 22nd of May, 1860.

JOHN HODGSON JONES was born in London on the 29th of April, 1823. It being decided that he should adopt the profession of engineering, he was placed as a pupil with the late Mr. T. Doe. After serving a regular apprenticeship to that gentleman, he was employed for four years under the late Mr. T. G. Barlow, in the erection of gas- and waterworks at Padua, Venice, and other places. His next engagement was one of three years under the late Mr. E. O. Manby,[1] on the construction of gasworks at Madrid, Valencia, and Malaga.

In 1849 Mr. Jones commenced to practise on his own account. The first work of importance he carried out was the drainage of the Duke of Bedford's estates at Wansford and Thorney. He was then engaged in the construction of waterworks at Arequipa in Peru; gasworks at Leatherhead, Malvern, and Banbury; waterworks at Banbury; and gas-, water-, and sewerage works at Thorney. He also designed gasworks for Bombay; Port Louis,

[1] Minutes of Proceedings Inst. C.E., vol. xxiv. p. 533.

Mauritius; Port Elizabeth, South Africa; Bari, Trapani and Marsala, in Italy; Corfu, in the Ionian Islands; and the new works at Valetta, Malta. In 1860 he was appointed Consulting Engineer to the Malta and Mediterranean Gas Company, which office he held for many years.

Mr. Jones also carried out water- and drainage works for Lord Calthorpe, at Elvetham Hall, Winchfield, in Hampshire, and waterworks at Arras, in France, and acted for a time as joint Consulting Engineer with the late Mr. George Lowe[1] to the European Gas Company. On the formation of the Continental Union Gas Company in 1864, Mr. Jones was appointed Consulting Engineer, which position he held until his death; and in December, 1868, on the decease of Mr George Lowe, he became sole Consulting Engineer to the European Gas Company. The Continental Company has works at Strasburg; at Albi, Cette, Nimes, Vienne, and other towns in France; and at Alessandria, Genoa, Moderna, Parma, Messina, and Milan, in Italy; and as Mr. Jones had to advise in connection with them all, it will be seen that his duties were by no means light or unimportant.

Mr. Jones died practically in harness on the 1st of December, 1892, at Kreuznach, Germany, from paralysis, brought on by anxiety to continue his work to the last. Amidst his many engagements he ever evinced, and encouraged in others, a high sense of honour and integrity. He was elected an Associate of the Institution on the 7th of May, 1850, and was transferred to the class of Member on the 24th of March, 1863.

JOHN LUNT, son of the late Mr. Joseph Lunt, was born at Chester, on the 14th of April, 1832, and at the age of twenty left England for Melbourne, where he set up in business as a builder and contractor. In 1858 he entered the service of the Victorian Government, in the Railway Department, in which he remained until his death.

This Department had then only recently been formed, so that Mr. Lunt's life may be said to have been spent in assisting in the initiation and development of railways in Victoria, some account of which is given in the obituary notice of the late Mr. Robert Watson.[2] For the first five years he acted as an

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[1] Minutes of Proceedings Inst. C.E., vol. xxx. p. 442.

[2] *Ibid*, vol. civ. p. 304.

Inspector of Works, and was then engaged for three years in the office, under Mr. Watson. From 1866 to 1871 he was occupied on surveys for new lines, and for the next seven years acted as District Engineer in charge of the construction of the North Eastern and Gippsland lines, with their branches. Mr. Lunt was then from 1878 to 1883 Engineer in charge of the maintenance of existing lines, and for the following four years Chief Assistant to the Engineer for existing lines. That position he held until January, 1887, when he was appointed Engineer of existing lines. He died from Bright's disease, on the 16th of March, 1892.

Mr. Lunt, although from the nature of his duties but little known outside the Victorian Railway Department, was an indefatigable worker, and gained the reputation of a reliable and painstaking official. He was elected a Member of the Institution on the 6th of December, 1887.

HENRY JOHN MARTEN, born on the 3rd of February, 1827, was the son of the late Mr. Robert Giles Marten, of Plaistow, Essex, and grandson of the late Mr. Robert Humphrey Marten, a London merchant, who was Deputy Chairman of the Commercial Dock Company, and a Director of the Kent Waterworks Company and of the East London Waterworks Company. He was educated at Mill Hill School and at the age of sixteen was articled to the late Mr. Thomas Wicksteed, Engineer to the East London Water Company, who at that time enjoyed an extensive private practice. When between eighteen and nineteen years of age, Mr. Marten was sent to Hull and subsequently to Wolverhampton where Mr. Wicksteed was constructing waterworks, and after a few months he took charge of the latter as Resident Engineer, although still a pupil. On the completion of the works the Directors of the company, who had formed a high opinion of Mr. Marten's abilities, requested him to continue in their service, formally appointing him as Engineer with the right of private practice.

For the next few years, although a very young man, he was largely concerned in the practice of hydraulic engineering. He carried out reservoir extensions for the Wolverhampton company, constructing for it, at Goldthorn Hill, near that town, what are believed to be almost the first covered service-reservoirs in this country. He also converted the service from intermittent to constant supply. In fact, he may be looked upon as one of the

pioneers of the system of "constant supply"; in the year 1850, when only twenty-three years old, he gave evidence before the General Board of Health upon the change he had recently brought about at Wolverhampton, with a view to show that with proper precautions the system might be advantageously applied to the Metropolis; and in the two following years he gave similar evidence[1] before the Parliamentary Committees on the Water Supply of the Metropolis presided over by Sir James Graham and Mr. William Beckett.

Mr. Marten, still residing and having offices at Wolverhampton, now began to enjoy a large practice. Before he had completed his twenty-eighth year he had constructed waterworks for the towns of Wellington (Salop), and Bridgnorth, and for the Stourbridge district. He also designed and carried out a sewerage scheme for the town of Bilston which was amongst the earliest drainage systems undertaken in this country. In all the above-named works he had the help, first as assistant and later as partner, of his younger brother, Mr. E. B. Marten. In conjunction with the late Mr. J. R. McClean,[2] M.P., Past-President Inst. C.E., he obtained the Act for the construction of the South Staffordshire Waterworks, and together they designed and carried out the earlier portions of that undertaking, which now supplies about 400,000 persons with water.

In the year 1854 Mr. Marten married the daughter of the late Mr. E. B. Dimmack, J.P., a large ironmaster in Staffordshire and South Wales; shortly afterwards he entered into partnership with his father-in-law, and for the next twenty years was occupied with the management of the Parkfield Ironworks and Collieries near Wolverhampton, in which he was largely interested. He was also frequently before Parliamentary Committees as a witness in connection with the coal and iron industries, his clear and lucid method of explaining technical subjects, together with his professional training, causing him to be greatly in request for this purpose.

In the year 1875, on the death of Mr. Dimmack, the Parkfield Iron Company was wound up. For some years previously Mr. Marten had occupied chambers at Storey's Gate, Westminster, which he now made his headquarters with a country office at Wolverhampton. Three years later he was retained on behalf of the Committee of Landowners who so actively opposed the

[1] Minutes of Evidence in Library Inst. C.E.

[2] Minutes of Proceedings Inst. C.E., vol. xxxviii. p. 287.

Thirlmere Water Scheme of the Manchester Corporation, and in the following year he was appointed Engineer to the Severn Commissioners, an office which he continued to hold to the day of his death. One of his earliest duties in this capacity was to guard the Commissioners' interests in connection with the proposal of the Corporation of Liverpool to impound the headwaters of the River Vyrnwy, a tributary of the Severn. The Compensation Clauses which were inserted in the Liverpool Water Bill of 1880, were practically the outcome of his suggestions and have subsequently been regarded as a precedent in similar cases. In 1890 he presented to the Geological Society, of which he was a Fellow, a Paper "On some Water-worn and Pebble-worn Stones taken from the Holt-Fleet Weir on the River Severn."[1] About this time Mr. Marten was appointed one of the three Statutory Arbitrators under the South Staffordshire Mines Drainage Acts, with Mr. G. M. Dowdeswell, Q.C., and Mr. Hawksley, Past-President Inst. C.E., as his colleagues, and subsequently he became engineer to the Staffordshire and Worcestershire Canal Company.

Amongst other important works designed and carried out by Mr. Marten may be mentioned the deep bore-hole in the Bunter Sandstones at Cosford for the Wolverhampton Corporation, from which between 3,000,000 and 4,000,000 gallons of water a day are now pumped. His report on this bore-hole to the Waterworks Committee of the Town Council of Wolverhampton is preserved in the library of the Institution.[2] He also carried out waterworks for the Tamworth District Sanitary Authorities at a cost of about £30,000; the Dudley Sewerage Works (an account[3] of which was presented to the Institution by his son, Mr. E. D. Marten), at a cost of £55,000; the West Gloucestershire Waterworks at a cost of between £70,000 and £80,000; the Tipton Sewerage Works at a cost of £15,000, and (in partnership with his son) the Tettenhall Sewerage Works at a cost of £14,000. At the time of his death he was engaged upon an important improvement of the Severn Navigation, under which, at an outlay of £30,000, the minimum navigable depth is being increased from 6 feet to 10 feet, and other works, including a dock at Worcester, are being carried out.

Mr. Marten had also a considerable practice as a consulting engineer. He acted in this capacity for the Corporations of

[1] *Geological Journal*, vol. xlvii. p. 63.
[2] Library Inst. C.E., Tracts folio, vol. xxi.
[3] Minutes of Proceedings Inst. C.E., vol. civ. p. 238.

Wolverhampton, Walsall, West Bromwich, and for the York Water Company, the Guardians of the Seisdon Union and other bodies. He was also consulted by the Corporation of Bristol with respect to the question of floods, by the Corporation of Shrewsbury as to water-supply, and on various matters by the Manchester Ship Canal Company, the River Dee Company, the Corporation of Windsor, the Staffordshire Potteries Water Company, and the Leeds and Liverpool Canal Company; and was retained by the Birmingham Corporation in support of its Water Bill during the Session of 1892. On several occasions he was consulted by the Conservators of the River Thames, and in the year 1891 he and Mr. Henry Rofe, prepared, by their direction, a scheme of impounding-reservoirs in the Upper Thames valley, whereby it was proposed to increase the dry weather flow of the river by 130,000,000 gallons a day. It was in connection with this scheme that Mr. Marten gave evidence before the Royal Commission on the Water Supply of the Metropolis only a few weeks before his death. It should also be mentioned that he held from 1885 the appointment of Engineering Inspector to the Land Commission for England, subsequently merged in the present Board of Agriculture.

In the year 1880 Mr. Marten, whose first wife had died in 1862, married the widow of the late Mr. William Pilkington, J.P. of Blackburn, and he then went to reside at The Birches, a country house about 4 miles from Wolverhampton. Here he had an office and was in the habit of coming when he had important reports to write or other work requiring undisturbed attention.

In the early part of 1892 Mr. Marten was taken seriously ill, and being advised by his medical attendant that complete rest was necessary, he travelled for three months on the Continent, and returned home apparently much improved in health. It is probable, however, that he never really rallied, and although seemingly quite well and cheerful to the last, he was seized with paralysis, and died after a short and painless illness on the 3rd of November, 1892, in his sixty-sixth year.

Mr. Marten was elected an Associate of the Institution on the 6th of April, 1852, and was transferred to the class of Member on the 21st of November, 1854. He was a frequent attendant at its meetings, and on several occasions took part in discussions on Papers dealing with drainage and sewerage, water-supply and the conservation of rivers. He was a Member of Council of the Royal Meteorological Society, in the work of which he always evinced great interest.

HENRY JOHN PAULING was born at Rochester on the 10th of March, 1821, and gained his first engineering knowledge and experience in the service of Messrs. G. C. Pauling & Co., engineers and contractors, of Manchester. After remaining with that firm for nearly ten years, he was appointed in 1853 an Assistant Engineer on the construction of the Roeskilde and Korsoer Railway in Denmark under Mr. W. G. Brounger, the representative of the contractors, Messrs. Fox, Henderson & Co. He had charge of a district of 25 miles, and on the completion of the work, in 1856, was entrusted by the same firm with the construction of the Portadown and Dungannon Railway in Ireland, upon which he was engaged for two years.

In 1859, the late Sir Charles Fox [1] having accepted the post of Engineer to the Cape Town Railway and Dock Company, Mr. Pauling was appointed District Engineer, under Mr. W. G. Brounger, in charge of the construction of about 25 miles of the Wellington Railway. In 1864, he became Resident Engineer of the whole of that line under the Company, a post which he continued to hold when the Colonial Government took over the railway in January, 1873. Important extensions having been sanctioned by Parliament, he was entrusted with the control of their construction, with an assistant in immediate charge of the open line as it advanced inland. In 1881 he was appointed Chief Resident Engineer of the western of the three colonial railway systems, and on several occasions acted as Railway Engineer for the Colony.

Mr. Pauling succeeded in 1885 to the appointment of Engineer-in-Chief of the Cape Government Railways, which he retained until his retirement in 1891. In the several capacities referred to he had charge of the construction of nearly 1,200 miles of railway in South Africa, while during the last six years of his term of office, he had chief control of the maintenance of the whole of the Government railways in the Colony, extending—at the time of his retirement—over upwards of 2,000 miles. He died at his residence near Cape Town on the 8th September, 1892, from bronchitis.

Mr. Pauling was a good judge of work, was in character cautious, and in manner genial and courteous, but retiring. He was held in high esteem by his superior officers, and looked up to with affection by his subordinates. He was elected a Member of the Institution on the 4th of May, 1880.

[1] Minutes of Proceedings Inst. C.E., vol. xxxix. p. 264.

JOHN HOOKE TAUNTON[1] was the youngest son of the late Mr. William Doidge Taunton, of Totnes, Devon, by his second wife Caroline, daughter of Mr. John Hooke Greene, Collector of Customs at the Cape of Good Hope, and was born at Totnes on the 8th of April, 1821. At seven years of age he was placed under the care of his grandfather, Mr. Greene, who resided in Bath, and was educated principally at a private school kept in that city by Mr. Joseph Shenstone, under whom he obtained not only an ordinary elementary acquaintance with classics and mathematics, but also some knowledge of physical science.

On leaving school he was apprenticed for five years to Messrs. Rofe and Son, Civil Engineers, of Birmingham, and during his pupilage obtained, in 1838, the silver Isis Medal given by the Society of Arts, for drawings, from actual measurement, of the pumping-engines at Aston of the Birmingham Waterworks Company, which had been constructed under the direction of Mr. Rofe, sen. In the following year he received from the same society a large silver medal for drawings of engines and machinery. At the request of Lieutenant Lecount, who was writing the article "Railways" for the seventh edition of the *Encyclopædia Britannica*, he made the drawings for the principal illustrations, including one of a six-wheel locomotive-engine constructed by Messrs. Sharp and Roberts, of Manchester. Towards the close of 1839 Mr. Taunton, whose health was suffering from too much confinement in the drawing-office, went to Preston in Lancashire, to the large gasworks of which town Mr. John Rofe, jun., was engineer, and there he acquired a fair knowledge of the construction and management of such works. Subsequently an arrangement was made for the completion of the remaining part of his apprenticeship with the late Mr. James Meadows Rendel,[2] Past-President Inst. C.E. Mr. Taunton subsequently remained as an assistant with Messrs. Rendel and Beardmore until the end of 1842, and was employed by them on surveys for railways and harbours, and on the construction of the Millbay Pier at Plymouth. Their high opinion of his qualifications was endorsed by Mr. Rendel on the articles of apprenticeship.

In December 1843 Mr. Taunton was elected, from among upwards of thirty competitors, Assistant Engineer to the Grand Junction Waterworks Company, which post, however, he resigned

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[1] This Notice is mainly autobiographical.—Sec. Inst. C.E.

[2] Minutes of Proceedings Inst. C.E., vol. xvi. p. 133.

in the following September. In the early part of 1845, while engaged in checking the levels of various projected lines, he discovered at St. Ives an error of 10 feet on the deposited section of the proposed Cambridge and Lincoln Railway, which led to its rejection on Standing Orders. Between April and September of the same year Mr. Taunton was in Ireland, levelling and laying out various railways, principally the Cork and Waterford line, to which the late Mr. I. K. Brunel [1] became Engineer. So satisfactorily was his work carried out that soon afterwards he was appointed one of Mr. Brunel's assistants, and was engaged in the London office of that gentleman during the busy session of 1846. He was then appointed District Engineer, under Mr. Brunel, on the Oxford, Worcester, and Wolverhampton Railway between Moreton and Oxford, which post he held until 1850, when the works were suspended. In September of that year Mr. Taunton undertook the construction by contract of new waterworks at Reading, which the old Company, acting on the advice of its Consulting Engineer, the late Mr. James Simpson,[2] Past-President Inst. C.E., had determined to erect. Another company, however, had succeeded in obtaining an Act of Parliament for the same purpose, and in order to stop its proceedings, as well as for his own protection, Mr. Taunton, without waiting for an Act, at once bought up all the bricks available in the neighbourhood and pushed forward with rapidity the large reservoir at Castle Hill and other necessary works, all of which were to be constructed on lands belonging to the old company or its shareholders or supporters. This proved effectual in stopping the new company, and the waterworks undertaken by Mr. Taunton were satisfactorily completed and brought into use during the summer of 1852, when he disposed of all his contractor's plant, with the view of confining himself to engineering practice strictly, in Gloucestershire and at a London office in Parliament Street, Westminster.

In August 1852 Mr. Taunton was appointed Engineer and General Manager of the Thames and Severn Canal Navigation, which office he held until 1885, when the entire control of the canal was assumed by the Great Western Railway Company, which some three years before had obtained the bulk of the shares in the Navigation. During the thirty years of Mr. Taunton's management, the Navigation was maintained in an active condition; a new engine for supplying the summit at

[1] Minutes of Proceedings Inst. C.E., vol. xix. p. 169.
[2] *Ibid*, vol. xxx. p. 457.

Thames Head was erected in 1854, various important works were carried out, regular trading boats were put on, and the tunnel at Sapperton, $2\frac{1}{3}$ miles in length, was repaired under circumstances of great difficulty. For the latter work he received, in 1880, a special letter of acknowledgment from the Committee of Management. Ten years previously he had read at a meeting of the Cotteswold Club, at the Royal Agricultural College, Cirencester, a Paper descriptive of this tunnel.[1]

In 1866 the Company applied to Parliament for the conversion of the canal into a railway in connection with the Midland system, a scheme which was stoutly opposed by the Great Western Railway Company. In the engineering work involved, which was considerable, Mr. Taunton was associated with Mr. W. H. Barlow, Past-President Inst. C.E. The Bill, after a long inquiry, passed the House of Commons, but was thrown out, after only two days, by the House of Lords. The Canal Company was thus left to maintain the competition as best it could with the Great Western Railway, whose line ran alongside the canal for a considerable distance, and to this end every effort was made by Mr. Taunton, with the full support of the canal proprietors. In 1871 a large property intervening between Stroud and the Midland Railway station at Dudbridge came into the market and was purchased by him, with the result that the Midland Railway has since been brought into Stroud, to the material advantage of the canal, the Stroud Wharf (the terminal wharf of the canal at its western end) being practically alongside the Midland Railway station. It having been ascertained that much trade was lost to the Navigation owing to the uncertainty of carriage by traders who possessed a virtual monopoly of the supply of boats, the Canal Company undertook, in 1875, the carrying trade to the extent of running boats with regularity for the accommodation and development of the traffic. This was done under the advice of Mr. Taunton and proved to be remunerative, haulage both by horses and steam-tugs being employed in localities where locks were not numerous.

Between 1853 and 1857 Mr. Taunton designed and superintended the construction of waterworks for the town of Llanelly, in South Wales, and about the same time he designed a system of sewerage and drainage for the same place. In September 1856 he was employed to report on the works of the Lancaster and Ulverstone Railway across Morecambe Bay,[2] designed and then

[1] Library Inst. C.E., Tracts 8vo. vol. 210.

[2] Minutes of Proceedings Inst. C.E., vol. xiv. p. 239, and vol. xvii. p. 442.

being carried out under the direction of the late Sir James Brunlees,[1] Past-President Inst. C.E. In the following year he was consulted by the Stroud Local Board of Health as to a system of sewerage and drainage for that district. As a preliminary, he made the necessary surveys and prepared the general and enlarged plans (the latter on a scale of 44 feet to the inch) of the district with the various levels, all of which were approved by the General Board of Health of that day. Towards the close of 1858 he submitted a design for a complete system of sewerage and drainage, with estimates, for a population of from 8,000 to 9,000; the works were commenced in May 1859, and completed, under Mr. Taunton's direction, in the autumn of 1861, at a cost of £5,243, including the purifying-tanks. Further extensions were carried out under his direction during 1864 and 1865, the spring-water by which the town is supplied being pumped into a high-service tank on a water-tower built in May of the latter year. At that time he was consulted by the Cheltenham Town Authorities as to the increased supply of water which the then existing company proposed to obtain from the Severn near Tewkesbury. Mr. Taunton disapproved of the project, and pointed out that a sufficient supply was obtainable within the amphitheatre of hills surrounding the town, especially by a fuller abstraction of water from the sources of the Chelt stream, some of which the Company had already taken. He formulated a plan called the Dowdeswell Scheme, which has since been carried out by the late Mr. J. F. La Trobe Bateman,[2] Past-President Inst. C.E., who was associated with Mr. Taunton in the prolonged parliamentary contests that ensued between the Waterworks Company and the Cheltenham Town Authorities. Between 1882 and 1884 waterworks were carried out at Cirencester under his design and direction. Mr. Taunton was also much engaged in general practice and in Parliamentary inquiries, relating principally to hydraulic engineering. In 1877 he gave evidence before the Committee of the House of Commons on the Prevention of Thames Floods, and also before the Committee of the House of Lords on Conservancy Boards, and in 1883 again before the Commons Committee on Canals.

Mr. Taunton was elected an Associate of the Institution on the 2nd of December, 1851, and was transferred to the class of Member on the 23rd of February, 1858. He was also a Fellow of the Geological Society, and an old Member of the Cotteswold Natu-

[1] Minutes of Proceedings Inst. C.E., vol. cxi. p. 367.
[2] *Ibid*, vol. xcvii. p. 392.

ralists Field Club, to the publications of which he contributed many Papers, including that on the "Sapperton Tunnel," already referred to, "A Description of the Malmesbury Waterworks," [1] and "The Hydrology of the Cotteswolds." [2] He also presented a Paper on "Bridges" [3] to the Stroud Natural History and Philosophical Society. In 1883 he reported to the Committee of the Associated Canals and Navigations on the "Wilts and Berks Canal, and Thames and Isis Navigation." [4]

Mr. Taunton died at his residence, Stuart House, near Stroud, after a short illness, on the 31st of January, 1893.

JOSEPH JULIUS CAZIMAJOU was born on the 10th of February, 1846, in Cuba, where his parents, who were French, had settled. At ten years of age, he was sent to France to be educated at the Lycée Impériale, Limoges, where he remained until 1865, taking the degree of B. ès Sc. He then studied for three years at the College of Architects, Madrid, and in 1869, was employed on the Cadastral Survey of Spain. On the completion of that survey, he returned to the West Indies, and was engaged for two years at Martinique, on the construction of the submarine telegraph between the Isthmus of Panama and the West Indian Islands. During that time he joined the army of the insurgents who, since 1868, had caused the Spanish Government so much trouble in Cuba. In 1872, the rebellion being for a time suppressed, Mr. Cazimajou was forced to take refuge in Jamaica, where he obtained employment under Mr. Thomas Farrer and Mr. F. Target, in making a survey for the Kingston Waterworks. During 1875 and 1876, he was Assistant Engineer under Mr. James Richmond on the Rio Cobre Irrigation Works in the Island of Jamaica. He was then appointed Professor of Civil Engineering in the Government College of Haiti, and while holding that post he designed and constructed some iron bridges and other works for the Haitian Government.

In 1879 Mr. Cazimajou returned to Jamaica, and was employed for eighteen months under Mr. William Climie on the contract

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[1] Library Inst. C.E., Tracts 8vo., vol. 274.
[2] *Ibid*, Tracts 8vo., vol. 433.
[3] *Ibid*, Tracts 4to., vol. 86.
[4] *Ibid*, Tracts folio, vol. 45.

for the reconstruction of the Jamaica Railway. On the completion of this work, he was appointed in March, 1881, Superintendent of Permanent Way, and subsequently Engineer of Way and Works on the Jamaica Government Railway, under Mr. Valentine G. Bell. On the transfer of this line to the Jamaica Railway Company, he was retained by the latter in the same office. In the spring of 1891, Mr. Cazimajou was prostrated by a stroke of paralysis, from which, however, he recovered; but a second attack unfitted him for any kind of work, and obliged him to retire from the service of the Jamaica Railway Company in February, 1892. He died in Cuba in the following July, at the comparatively early age of forty-six.

Mr. Cazimajou was a man of good education, an able Engineer, and thoroughly conscientious in his work. Of genial disposition and kind heart, he made many warm friends. With his subordinates he was very popular, while at the same time a strict disciplinarian and careful to exact good and faithful work. As a son and brother his conduct was exemplary; for several years he lived a struggling life in order to support his aged parents and unmarried sisters. Mr. Cazimajou was elected an Associate of the Institution on the 6th of April, 1886.

GEORGE HOWARD CLARKE, third son of the late Mr. H. B. Clarke of Serjeant's Inn, solicitor, was born on the 5th of September, 1849. After being educated at Kensington Grammar School, he served an apprenticeship of five years with the Yorkshire Engine Company of Sheffield, and then worked for a time in the construction and repairing-shops of the Manchester, Sheffield, and Lincolnshire Railway at Gorton. In 1875 he was appointed District Locomotive Superintendent at Grimsby for the Manchester, Sheffield, and Lincolnshire Railway Company, under the late Mr. Charles R. Sacré,[1] Chief Engineer. That post he held for thirteen years, his duties including the supervision and maintenance of locomotives, of hydraulic and dredging machinery, and also of the Company's fleet of steamers working between Grimsby and the Continent.

In 1887 Mr. Clarke obtained the appointment of Locomotive Superintendent to the Argentine Great Western Railway Company, and in the following year that of Locomotive Superintendent

[1] Minutes of Proceedings Inst. C.E., vol. xcviii. p. 399.]

to the Great Southern of Santa Fé and Cordoba Railway Company. The latter post he held until the spring of 1891, when a reduction in the staff and salaries induced him to resign. After some months' stay in England he returned to South America in February, 1892, as Locomotive Superintendent of the Minas Central of Brazil Railway. He never, however, entered upon the duties of this post, as he was attacked, at Cruzerio, by yellow fever, which proved fatal on the 9th of March, 1892.

Mr. Clarke was a competent engineer and enthusiastically devoted to his work. In disposition he was kind, generous, and sympathetic. He was married in 1882 to Annie, eldest daughter of Mr. J. P. Atkinson, J.P., of Scartho, near Grimsby. He was elected an Associate Member of the Institution on the 3rd of December, 1889.

JOHN DOUGLAS was born at Cupar, Fife, N.B., on the 20th of March, 1836, and was educated at the Universities of St. Andrews and Edinburgh. After serving articles to the late Mr. Jesse Hall, Civil Engineer, of St. Andrews, he went, in 1859, to Dublin as Assistant Engineer to the Hibernian Gas Light Company. That post he held until the end of 1862, when he was appointed Engineer and Manager of the Portsea Island Gas Company at Portsmouth. Mr. Douglas subsequently undertook also the duties of Secretary, and during his management the works of the Company were entirely remodelled and greatly extended. A river-wall and new gasholders, in which concrete was used in the construction of the tanks, were among the works he carried out, in addition to the introduction of coal-lifting machinery.

Mr. Douglas was compelled by an attack of paralysis to resign his connection with the Portsea Island Gas Company in 1879, and for the next six years he was unable to engage actively in the pursuit of the profession. In 1885, however, he had so far recovered as to undertake the management of the Medina Cement Works, near Newport, I.W., of Messrs. Charles Francis, Son, and Co., in which firm he had been a partner for some ten years. But his health never became entirely re-established, and after intervals of suffering he died at Cowes on the 10th of January, 1892.

Mr. Douglas was an active member of the British Association of Gas Managers, to the Proceedings of which he contributed several Papers, receiving the President's Medal in 1875 for one entitled "The Systematic Testing of Consumers' Meters." He served the office of President of the Association during the Session

1879–80. Prior to his illness he contributed to the Portsmouth Club several Papers on Electricity, a subject in which he took great interest.

Mr. Douglas was elected an Associate of the Institution on the 3rd of February, 1874, and was transferred to the class of Associate Member on its creation in December, 1878.

HENRY COLTHURST GODWIN, second son of the late Mr. James Godwin of Huntworth, Stoke Bishop, near Bristol, was born at Stoke Bishop on the 18th of September, 1858. He was educated at Clifton College, on leaving which in 1877 he went for a voyage to Australia, returning to England by way of San Francisco. After serving for six months with Messrs. Waddell and Co. on the construction of the Llanelly and Mynyddmawr Railway, he passed through the three-years course in engineering at the University of Edinburgh. In 1882 he went to Manitoba, and two years later obtained a commission as Dominion Land Surveyor, after which he was engaged on the Manitoba and North West Railway, on the Canadian Pacific Railway and on drainage and bridge work in Manitoba for the Dominion Government. In 1886 he paid a short visit to England and also spent some months in China. For the next two years he was in the United States engaged on the survey, location, and construction of the St. Paul, Minnesota and Manitoba; the St. Paul and Duluth; and other railways.

In 1889 Mr. Godwin proceeded to Buenos Ayres, where he served for a time under Messrs. Hume Brothers, contractors, and was then employed by the Government of the Argentine Republic to make a survey of the Uruguay river in view of proposed canalization. He was returning to England on business connected with an island in the La Plata river which he had bought, when he was attacked by yellow fever and died at sea after a short illness on the morning of Christmas Day, 1891.

Mr. Godwin was the author of "The Railroad Engineers' Field-Book," published in 1890 by Messrs. Wiley and Co., of New York, and at the time of his death had just completed another work, as yet unpublished, entitled "Field Instruments and Field-work." He was elected an Associate Member of the Institution on the 13th of January, 1891.

HENRY NICHOLAS HARVEY, eldest son of the late Mr. Nicholas Oliver Harvey,[1] senior partner and managing engineer of the firm of Messrs. Harvey and Co. of Hayle, Cornwall, was born on the 3rd of June, 1857. He was educated at Allhallows School, Honiton, at Malvern College, and at King's College, London, after which he was practically trained in the shops and drawing-office at Hayle, under the late Mr. William Husband,[2] who, on the death of Mr. N. O. Harvey, had become managing partner of the firm. In January, 1882, he took charge of the Company's office in London, where he remained until 1885, when he returned to Hayle to assist in the management of the engineering department, of which he became chief two years later. During the period of his management extensive additions and improvements were made, notably in the forge, machine-shop, and shipbuilding and boiler-making departments, which enabled the firm to build steamers of carrying capacity up to 4,000 tons.

Mr. Harvey also took great interest in the improvement of mining machinery, particularly in the adoption of iron pump-rods in place of the cumbersome wooden ones, of revolving stamps and of compound-winding and air-compressing machines. Shortly before his death he erected revolving-stamps at the Dolcoath Mines in Cornwall. He was much interested too in the construction of Cornish-boilers, on which subject he read shortly before his death an exhaustive Paper before the Mining Institute of Cornwall. In April, 1891, he was appointed a Justice of the Peace for the county. But unfortunately his career was destined to be cut prematurely short. For some six years he had suffered from an affection of the lungs which ended fatally on the 14th of December, 1892.

Mr. Harvey possessed great force of character and was energetic and determined in the prosecution of his work—qualities which are the more noteworthy when the state of his health, never very robust, is taken into consideration. He was a kind and considerate master and socially a great favourite. Mr. Harvey was elected an Associate Member of the Institution on the 9th of January, 1883.

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[1] Minutes of Proceedings Inst. C.E., vol. xxi. p. 558.

[2] *Ibid*, vol. lxxxix. p. 470.

CHARLES HERBERT HOPKINSON, second son of Mr. James Hopkinson, of Bury, Lancashire, was born on the 15th of July, 1858. After serving articles to Mr. Alfred Hopkinson of the same town, he joined in January, 1879, the staff of the late Mr. Ralph Firbank,[1] the contractor, with whom he remained for over four years. The first work upon which he was engaged was the widening of the London and North Western Railway from Manchester to Barton Moss, the embankment for which extends over a portion of Chat Moss. On the completion of that work he was occupied from May, 1880, to April, 1883, on the Lincoln and Sleaford extension of the Great Northern and Great Eastern Railways, which involved some heavy excavation and the construction of several large iron bridges. On the death of Mr. Firbank, at the end of 1882, he took charge of the completion of this contract and made the final measurements.

In May, 1883, Mr. Hopkinson proceeded to the Cape, where he was employed on the completion of the Grahamstown and Port Alfred Railway, a line 43 miles in length involving some heavy work and an expenditure of £300,000. He designed and erected all the temporary bridges and had charge of the locomotive and rolling-stock. From September, 1884, to November, 1885, he was engaged on the construction of the Queenstown and Aliwal North Railway, 90 miles in length.

Mr. Hopkinson left South Africa at the end of 1885, and early in the following year proceeded to the Argentine Republic to take up an appointment as District Engineer on the Buenos Ayres Great Southern Railway. His ability, energy, and success in the management of men were soon recognized and he was placed in charge of the most important section of the line. The services of contractors were dispensed with and the Company itself carried out the construction of new branches and extensions. Mr. Hopkinson had completed the branch from Cañuelas to Lobos and was proceeding with other extensions, when he died suddenly at Buenos Ayres on the 27th of September, 1892, from aneurism of the heart.

Mr. Hopkinson owed his position to a combination of indomitable perseverance and great self-reliance; and there can be little doubt that his early death cut short a career of much promise. He was elected an Associate Member of the Institution on the 18th of May, 1886.

[1] Minutes of Proceedings Inst. C.E., vol. lxxii. p. 317.

GEORGE MORGAN LANE, born on the 31st of May, 1856, was the youngest son of the late Mr. Michael Lane,[1] a former Engineer-in-chief of the Great Western Railway. At the age of eighteen he was articled to Messrs. Stothert and Pitt, of Bath, for three years, during which time he passed through the fitting-shop, foundry, smiths'-shop, and drawing-office. In 1877 he went to the Cape and served for a time as an Assistant Engineer on the Western Province Railways, under the late Mr. Henry J. Pauling (*ante* p. 359), and then in a similar capacity on the Orange River bridges erected by Messrs. Westwood, Baillie, and Co., for the Public Works Department of the Cape of Good Hope. On the completion of that work, he obtained in 1880 an appointment in Brazil, as an Assistant Engineer on the Pará Waterworks and Engineer-in-charge of the Custom House Jetty. These posts, however, he resigned in the following year, in order to visit the United States with the object of acquiring a knowledge of the American system of bridge-building.

Mr. Lane's visit to the United States was destined to become a residence of six years. For some months in 1881 he acted as an Assistant Engineer on the Northern Pacific Railroad, under General Anderson, and was then for two years with the Milwaukee Bridge Company as Chief of Erectors and Assistant Superintendent of the shops. In 1884 he was occupied for a short time in designing for the Keystone Bridge Company, and in the two following years was engaged on general work for the Morgan Engineering Company. Towards the end of 1866 he was appointed Engineer to the Detroit Patent Foundry Company, but during the latter part of his residence in the States he had become greatly interested in copper mining, and in the following year he relinquished this post for that of Engineer to the Bede Metal Company's mines at Valdelamusa, near Huelva, in Spain. Mr. Lane remained in charge of these mines until 1890, when he was commissioned by the Cuba Fibre Company of London, to report upon special machinery requisite for the development of the fibre industry, and it was during a second visit to Cuba that he had the misfortune to contract yellow fever, from which he died at Nuevitas on the 24th of October, 1892, at the early age of thirty-six.

Mr. Lane's ability as an engineer gave promise of a successful career, and all with whom he came into contact bear testimony to his upright, frank, and kindly disposition as a man. He was elected an Associate Member of the Institution on the 7th of February, 1888.

[1] Minutes of Proceedings Inst. C.E., vol. xxx. p. 441

ALFRED PERRY, who was born at Taunton in 1834, gained his first professional experience in the office of the late Mr. J. S. Cockings of Birmingham, Consulting Engineer and Patent Agent. After spending four years there he was engaged for twelve months as a draughtsman in the iron building and roofing works of Mr. J. H. Porter at Birmingham. He was then employed in a similar capacity from 1857 to 1861 at the Ashbury Railway Carriage and Wagon Works, Manchester, and subsequently for twelve months by Messrs. Chance Brothers & Co., the lighthouse engineers of Birmingham. From 1862 to 1864 he was an assistant in the works of Messrs. Ormerod, Grierson & Co., of Manchester, and was then for three years assistant manager to the Birmingham Railway Carriage and Wagon Company.

In 1867 Mr. Perry re-entered the service of Messrs. Chance Brothers & Co., with whom he remained until his death. He became chief of the drawing office, and during his long connection with the firm assisted in the design and execution of dioptric apparatus and of iron lighthouse towers, more particularly as to the mechanical details. In this work he was associated successively with Mr. J. T. Chance, Dr. John Hopkinson and Mr. James Kenward, and his great natural ability and long experience were of considerable service to lighthouse authorities in all parts of the world.

Mr. Perry died from heart disease on the 12th of December, 1892, after an illness of two months. An accomplished draughtsman and good mechanic, he was untiring in his efforts to bring to perfection whatever he undertook, and was faithful and loyal to the employers he served for so many years. Mr. Perry was elected an Associate of the Institution on the 4th of December, 1877, and was transferred to the class of Associate Member on its creation in the following year.

JOHN RICHARD HUTCHINSON WILLIAMSON, son of the late Mr. John Williamson of Darlington, was born on the 6th of August, 1859, and was educated at the Durham College of Science, Newcastle-on-Tyne, which represents the Faculties of Science and Engineering in the University of Durham. There he took honours in mathematics and physics, and came out first in the final examination for the Associateship in Science, with the Charles Mather Scholarship of the annual value of £40, tenable for two years.

After spending five years in the works of the Darlington Wagon and Engineering Company, he was appointed in July, 1882, Electrician to the Metropolitan Brush Electric Light Company, for which firm he installed electrical plant at the Royal Mint and carried out other important works in London. He held this post until November, 1883, after which he practised for a time as a Consulting Engineer.

In October, 1884, Mr. Williamson was appointed, out of seventy candidates, Engineer and Manager to the Manchester Edison-Swan Company, for which he successfully carried out the entire incandescent lighting of the Manchester Exhibition and a large number of installations in cotton-mills, warehouses and private mansions. To such a position did the Company attain under his management that the Board elected him Managing-Director in 1888, which office he was unfortunately compelled by ill-health to resign in the following year.

Under medical advice, Mr. Williamson left England for New South Wales in October, 1889, and by the following March had so far recovered as to be able to assume the post of Managing Director of the Williamson Electrical and Engineering Company, which had been formed by a few gentlemen who took great interest in his career. He soon obtained some important contracts in and around Sydney, amongst the works he carried out for the Company being the electric lighting of the Empire Hotel, the Garrick Theatre, the Imperial Arcade and Arcade Street in that city, and the Central Station lighting of the borough of Redfern. The strain was, however, too great, and the lung trouble from which he had been suffering became so acute that he was obliged to relinquish work entirely. In the autumn of 1892 he left Sydney and took up his quarters in a vineyard cottage at Allandale on Hunter River. For a time he appeared slightly better; but on the 7th of December, after his evening meal, hæmorrhage set in and he passed away in sleep at noon on the following day.

Mr. Williamson was a Member of the Institution of Electrical Engineers and of the Manchester Literary and Philosophical Society. He was elected an Associate Member of this Institution on the 6th of March, 1888.

CAPTAIN EDWARD KILLWICK CALVER, R.N. (retired), F.R.S., was born at Southwold on the 6th of December, 1813. At fifteen years of age he entered the navigating branch of the Royal Navy, on board H.M.S. "Crocodile" and for seven years was on foreign service in the East Indies and on the coast of South America. Returning to England in 1836, he joined the Hydrographic Department of the Navy and commenced his long period of service as a marine surveyor on home stations. For thirty-six years, with scarcely a break, he carried out these duties mainly on the north and east coasts of Great Britain. He was employed in this capacity first under the late Commander Slater, R.N., and then under the late Rear-Admiral Washington[1] (subsequently Hydrographer to the Admiralty), in surveying various harbours and rivers and also upon a general survey of the North Sea. From 1847 to 1872, he was in charge of the survey of the north and east coasts of England and Scotland and produced charts of nearly the whole of the eastern coast. The principal rivers and harbours were surveyed, as well as the outlying sandbanks and channels, which owing to their liability to constant change had to be repeatedly examined. He was promoted in 1863 to the rank of Staff-Commander and in 1870 to that of Staff-Captain.

In 1869 the deep waters of the Atlantic were dealt with, soundings and temperatures at depths of 100 fathoms to nearly 3 miles were determined and large quantities of the bottom, with its living organisms, were dredged up under the superintendence of Captain Calver. These operations were continued during the following summer and carried into the Mediterranean as far eastward as Malta. Very full and interesting details of these expeditions were communicated to the Royal Society by Dr. W. B. Carpenter, Mr. Gwyn Jeffreys, and Sir Wyville Thomson in reports[2] published in 1869 and 1870 of the scientific explorations of H.M. surveying-ship "Porcupine," and an account was also given in Sir Wyville Thomson's "Depths of the Sea." On the completion of a survey of the Wash, he retired in 1872 from active service in the Royal Navy with the rank of Captain. In the following year he was elected a Fellow of the Royal Society.

Captain Calver's constant employment in connection with the rivers and estuaries of the East Coast gave him great experience

[1] Minutes of Proceedings Inst. C.E., vol. xxiii. p. 513.

[2] Proceedings Royal Society, vol. xviii. p. 397 and vol. xix. p. 146

in the action of tides, waves and running water, and he devoted much time to the study of the principles to be observed in the improvement of tidal harbours and entrances. His views on this subject were set forth in various pamphlets, the most important being that on "The Conservation and Improvement of Tidal Rivers,"[1] published in 1853. He made several valuable reports to the Admiralty on harbours of refuge, his predictions as to the results of various works having nearly all been verified.

Although Captain Calver had retired from active service he continued to take great interest in all questions relating to the Navy, to harbours, and to the protection of ships on sea-shores. In 1876 he wrote a pamphlet entitled "The Cry for National Harbours, and its Connection with our Defective System of Public Harbour Legislation,"[2] which attracted much attention, as it was chiefly directed against the then proposed extension of Dover Harbour.

The latter years of Captain Calver's life were passed abroad and he died at Vevey in Switzerland on the 28th of October, 1892. He was elected an Associate of the Institution on the 10th of April, 1866, on the ground that, having made the physical laws in operation round our coasts the subject of special study, and having directed the experience thus gained into a practical channel by his writings, he was enabled to concur with Civil Engineers in the advancement of professional knowledge.

JOHN STINSON FARMER, born in 1827, entered at an early age the service of the London, Brighton and South Coast Railway Company; and in 1849 was appointed Assistant Traffic Manager of that line under the late Mr. George Hawkins.[3] He held that post for thirteen years; and during the prolonged absence of Mr. Hawkins, through ill-health, was responsible for the management of the whole of the extensive traffic of the Brighton Company.

In 1862 Mr. Farmer entered into partnership with Mr. John Saxby, a colleague in the service of the London, Brighton and South Coast Railway Company, and with him founded the business for the manufacture of railway signals and safety-appliances which

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[1] Library Inst. C.E.

[2] Library Inst. C.E. and *The Engineer*, vol. xlii. p. 251.

[3] Minutes of Proceedings Inst. C.E., vol. xcv. p. 397.

has since become so well known and so important. Works were erected at Kilburn, adjoining the London and North-Western Railway, and soon became the centre of an extensive industry. Mr. Saxby's interlocking system provided a mechanical reciprocating communication and action upon all the points and signals of a railway junction, whereby not only those points and signals which were in direct relation to one another were made to work in harmony, but all the other signals of the system were at the same time controlled and locked against improper or dangerous use. The first apparatus, introduced at Bricklayers' Arms, consisted of eight semaphore signals; and there were six pairs of points concentrated within the signal-cabin, all so governed and locked that it was impossible to give any signal contrary to the position of the points or in conflict with other signals. This was described by Mr. Farmer in the course of an interesting discussion at the Institution in 1874 upon a Paper [1] on "The Fixed Signals of Railways," by Mr. R. C. Rapier. In previous methods the locking was effected by the movement of the lever and if the apparatus became slack, the man in charge might be able to lower the signal at a wrong time; but in 1867 the firm introduced a most important invention, by means of which the locking was effected by the movement of the spring catch and a wrong signal could not be given, either by negligence or by slackness of the apparatus.

In 1875 Messrs. Saxby and Farmer brought out a continuous mechanical brake which attracted some attention at that time. Each vehicle was supplied with the brake apparatus, which consisted of rods worked by means of a four-way crank, in one arm of which a long slot was cut out for the purpose of connection. In attaching the couplings, which were fixtures, the brakes could be applied at either end of the train, or from all parts at once or separately; so that no matter into how many parts a train might be divided, each part was under the control of the brake and each wheel could be skidded, all that was required to be done being to slip the end of the heavy weight. The result was continuity of brake-power; so that, should the train part in two when in motion, the portion no longer attached to the engine was brought automatically to a standstill.

Among the various safety-appliances which Mr. Farmer assisted in bringing out may be mentioned the united lock and block-working apparatus, the ground-locking apparatus and several

[1] Minutes of Proceedings Inst. C.E., vol. xxxviii. p. 142.

telegraphic block instruments; and there can be no doubt that the present rapid and safe travelling on railways is due in a great measure to the firm with which he was so intimately connected for upwards of thirty years. Mr. Farmer died suddenly, from heart disease, at Ifold, near Billingshurst, in Sussex, on the evening of the 12th of December, 1892.

He was elected an Associate of the Institution on the 1st of December, 1868.

MAJOR HENRY GEFFCKEN KUNHARDT, R.E., son of the late Mr. G. E. Kunhardt of Staten Island, New York, U.S.A., and Elizabeth, daughter of the late Mr. Stephen Moulton, J.P., of Bradford-on-Avon, was born at Staten Island on the 6th of November, 1850, and was educated at Dr. Schleiden's school at Hamburg and at the Somersetshire College, Bath. From the latter he proceeded in 1869 to Woolwich Academy, fourth out of one hundred and forty competitors, was placed first in the half-year's examination and on the 12th of July, 1871, passed out first, with 29,614 marks, taking a regulation sword for exemplary conduct, the Pollock Gold Medal for distinguished proficiency and prizes for military drawing and gymnastics. The Inspecting Officer remarked that it was "very pleasing to find that one of the cadets, Mr. Kunhardt, had carried off so many prizes, in addition to having gained the highest number of marks, an example which they would do well to emulate."

The usual term having been served at Chatham, Lieutenant Kunhardt left for India on the 1st of July, 1873, viâ New York and the United States, visiting China and Japan and arriving in Calcutta in November. On the 22nd of December he was gazetted to the Public Works Department as Assistant Engineer, 2nd-Grade, and was posted to the Punjab Irrigation Branch on the Delhi Division of the Western Jumna Canal. Having seen works of great importance at home and visited most of the largest engineering works in the United States, he was much disappointed at the prospect of his duties being confined to inspecting periodically a few hundred miles of canal distributaries. In January, 1874, therefore he obtained a transfer to the Punjab Northern State Railway, whence two months later he was again moved to Sir Richard Temple's Bengal Famine Relief Works which took the form of a railway in the province of

Tirhoot. For his services in connection with the rapid and successful completion of this railway to Durbhanga he was commended by the Government of India and was promoted to Assistant Engineer, 1st-Grade, on the 18th of April, 1874. Lieutenant Kunhardt remained on the Tirhoot Railway until April, 1877, when his services were lent to the Agent of the Governor-General of Beluchistan for employment in Khelat. Meantime he had passed the Lower and Departmental Standard Examinations and had attended the Camp of Exercise at Delhi. During the time Lieutenant Kunhardt was lent to the agent for employment at Khelat he spent nine months at Quetta, where he was stabbed in both shoulders by a fanatic, whilst laying out the grounds for the Residency. In March, 1878, he returned to the Tirhoot State Railway; was transferred in the same month to the Patna-Gya Railway; and in the following month was promoted to Executive Engineer, 4th-Grade, temporary.

In November, 1878, Lieutenant Kunhardt was attached as Assistant Director to the North Eastern System of State Railways. In the following April he passed the Higher Standard Examination and in August was appointed Deputy Consulting Engineer to Guaranteed Railways at Lucknow. Three months later he was posted to the Rajputana Railway as Assistant Manager, and was confirmed as Executive Engineer, 4th-Grade, in January, 1880. In the same year he passed with high proficiency in both Urdu and Hindu. He was lent to the Durbhanga Raj from October, 1880, to August, 1884, during which period he designed and built the Palace at Durbhanga. In September, 1884, Captain Kunhardt, who in the previous year had obtained his company, was re-appointed to the Tirhoot State Railway and posted to Hajipore in charge of the large bridge then in course of construction over the River Gunduk, being promoted to Executive Engineer, 3rd-Grade, in October of the same year. His health failing, he obtained furlough from the following December. In January, 1885, he was promoted to Executive Engineer, 2nd-Grade, *sub. pro. tem.*, and in February, being in England on leave, he volunteered for service in Egypt and was placed on the British establishment until the following June, when he was restored to the Indian establishment. Captain Kunhardt proceeded to Suakim with the 10th Company and had only just commenced the railway thence to the front when all work was suspended. He therefore went on to India and was appointed to the Sind-Pishin State Railway in June, 1885. In November of that year he was granted furlough. Electing for continuous service in India he was confirmed as

Executive Engineer, 2nd-Grade, in July, 1886. He passed the preliminary examination in Russian, and then spent some months in Russia for further study. He obtained additional furlough and qualified as Interpreter in Russian, taking the prize of £200 offered by the Government.

When Captain Kunhardt returned to India in October, 1887, he was attached to the office of the Director General of Railways and in the following March was re-appointed to the Tirhoot State Railway, this time as Manager and Engineer-in-Chief, which posts he held until February, 1890, being twice commended by the Government of India for his management of the line. He obtained his majority on the 1st of November, 1889.

In the following year Major Kunhardt was offered the appointment of Agent to the East Indian Railway Company, which he would probably have accepted had not a more lucrative one been made by the Burma Ruby Mines Company, to which his services were lent from the 26th of November, 1890. His work in Burma was most successful, but was unfortunately cut short by an attack of dysentery which compelled him to leave for home in September, 1892. He only got as far as Marseilles, where his wife met him and where, after lingering a week, he died on the 4th of November, 1892, within two days of his forty-second birthday.

Major Kunhardt was a man of great ability and wonderful industry, devoted to study and never happier than when at work. He had great facility in acquiring languages and carried off many of the prizes offered in India for proficiency. He obtained the medal, with clasp and bronze star, for the Soudan Expedition of 1885. Always ready to obey orders, however unwelcome or distasteful, his superiors had only to say what was required and, if it were possible to do it, he would carry the work to a successful issue. He was elected an Associate of the Institution on the 2nd of December, 1879.

JOHN SOMERVILLE, born in Scotland in 1832, was first employed in a subordinate capacity at the Wolverhampton Gasworks. He then proceeded to London and entered the service of the Commercial Gas Company. From 1859 to 1869 he acted as Engineer and Manager to the Maidstone Gas Company, during which time he reconstructed and rebuilt the works, erecting a gas-holder and tank and adding new apparatus and machinery. He also

designed and constructed gasworks at East Peckham and Sittingbourne in Kent and chemical works at Marston in the same county.

In January, 1869, Mr. Somerville was appointed Engineer to the Dublin Gas Company, which office he held until 1874. For the next four years he was engaged in the management of gasworks at Newbridge, Mullingar, Roscrae, Thurles and Kilkenny. In 1878 he left Ireland and was for a few months employed at Rotherhithe by the Surrey Consumers Gas Company, which, in the following year, was amalgamated with the South Metropolitan Gas Company. He joined the united companies, and when the Phœnix Gas Company was also incorporated he took charge of the works at Bankside, Southwark. In addition to the duties of this post he devoted a considerable amount of time and ability to assisting Mr. George Livesey, then Chief Engineer to the South Metropolitan Gas Company, in the preparation of various drawings for the first of the series of large gasholders erected at the Old Kent Road Works. He held the post of Manager at Bankside until his death, which took place after a few hours' illness on the 15th of December, 1892.

Mr. Somerville was the inventor of several clever contrivances for improving the details of gas manufacture and was also one of the first to introduce a stoking machine, while in charge of the Dublin Works. He was a great advocate of generating and regenerating furnaces, which he was the means of introducing into several works on the Continent and in America. In disposition he was kind and straightforward, alike to his employers and to those working under him. He was elected an Associate of the Institution on the 13th of January, 1874.

*** The following deaths have also been made known since the 20th of February, 1893:—

Members.

Austin, Charles Edward; *died* 8 April, 1893, *aged* 73. (*Congestion of the lungs.*)

Blackett, John; *died* 8 January, 1893, *aged* 74.

Clarke, Thomas Charles; *born* 28 April, 1838; *died* 26 March, 1893.

Cowper, Edward Alfred; *born* 10 December, 1819; *died* 9 May, 1893. (*Pneumonia.*)

Fowler, Francis; *born* 28 June, 1829; *died* 9 February, 1893. (*Dysentery.*)

Griffith, William Charles Easton *born* 24 June, 1854; *died* 3 May, 1893. (*Heart disease following rheumatic fever.*)

Hewitt, John Richardson; *born* 28 April, 1842; *died* 27 March, 1893. (*Pneumonia following diabetes.*)

Mackinlay, John; *born* 10 July, 1823; *died* 22 April, 1893. (*Syncope.*)

Robson, Richard Oswald; *born* 21 July, 1826; *died* 21 March, 1893.

Associate Members.

BEDLINGTON, PETER ROE; *born* 18 April, 1856; *died* 4 April, 1893. (*Bronchitis.*)

NEALE, DEODATUS HILIN; *born* 5 September, 1849; *died* 5 April, 1893. (*Cerebral meningitis.*)

ROGERS, ARCHIBALD COLIN CAMPBELL; *born* 7 November, 1849; *died* 17 August, 1892. (*Enteric fever.*)

TREWHELLA, CHARLES ROBERT; *born* 14 March, 1865; *died* 8 March, 1893.

WILSON, GUILLERMO ANDRES; *born* 15 August, 1852; *died* 7 March, 1893. (*Inflammation of the liver.*)

YOUNG, BARCLAY HUGHES; *born* 7 October, 1854; *died* 27 April, 1893. (*Riding accident.*)

Associates.

FINDLAY, *Sir* GEORGE; *born* 18 May, 1829; *died* 26 March, 1893. (*Calculus.*)

PALMER, *Major-General* HENRY SPENCER, R.E. *retired; born* 13 April, 1838; *died* 11 March, 1893.

RANSOME, FREDERICK; *died* 19 April, 1893, *aged* 75.

ROBERTS, ROBERT WILLIAM; *born* 4 September, 1830; *died* 27 February, 1893. (*Bright's disease.*)

SMITH, *Major-General* PERCY, R.E. *retired; born* 15 June, 1838; *died* 25 April, 1893.

SPARKS, *Colonel* JOHN BARNES, B.S.C.; *born* 19 July, 1841; *died* 6 March, 1893. (*Bright's disease.*)

Information as to the professional career and personal characteristics of any of the above is solicited in aid of the preparation of Obituary Notices.—SEC. INST. C.E., 31 May, 1893.

Sect. III.

ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

On Magnesia Bricks. By C. Bischof.

(Oesterreichische Zeitschrift für Berg- und Hüttenwesen, 1893, p. 27.)

For the manufacture of magnesia bricks, the material most in favour at present is the magnesite of the Veitschthal, in Styria, which, although less pure considered as a source of magnesia than the same mineral from the island of Eubœa, in the Greek Archipelago, has the property of fritting at a high temperature without melting. This is due to the presence of iron and, probably, aluminium in small quantity. The composition of the two substances, both in the natural and burnt states, is as follows :—

Magnesite.	Styrian.	Greek.
	Per Cent.	Per Cent.
Carbonate of magnesia . . .	90·0 to 96·0	94·46
„ lime	0·5 „ 2·0	4·40
„ iron	3·0 „ 6·0	FeO 0·08
Silica	1·0	0·52
Manganous oxide	0·5	Water 0·54
Burnt Magnesite.		
Magnesia	77·6	82·46—95·36
Lime	7·3	0·83—10·92
Alumina and ferric oxide . .	13·0	0·56— 3·54
Silica	1·2	0·73— 7·98

The calcination may be effected in cupolas with a silicious lining in reverberatory furnaces, or, best, in highly-heated gas-kilns, the nature of the product varying with the amount of heat to which it is subjected. At a red-heat magnesium carbonate is decomposed into carbonic acid and caustic magnesia, which resembles lime in becoming hydrated and recarbonated when exposed to the air, and possesses a certain plasticity, so that it can be moulded when subjected to a heavy pressure. By long-continued or stronger heating the material becomes dead burnt, giving a form of magnesia of high density, sp. gr. 3·8, as compared with 3·0 in the plastic

form, which is perfectly unalterable in the air but entirely devoid of plasticity. According to Schlossing, a mixture of two volumes of dead-burnt with one of plastic magnesia can be moulded into bricks which contract but little in firing. Other binding materials that have been used are clay up to 10 or 15 per cent., gas-tar, perfectly freed from water, soda, silica, vinegar as a solution of magnesium acetate which is readily decomposed by heat, and carbolates of alkalies or lime. Among magnesium compounds a weak solution of magnesium chloride may also be used. For setting the bricks lightly-burnt, caustic magnesia, with a small proportion of silica to render it less refractory, is recommended. The strength of the bricks may be increased by adding iron, either as oxide or silicate. If a porous product is required, sawdust or starch may be added to the mixture. When dead-burnt magnesia is used alone, soda is said to be the best binding material.

At Brieg, in Silesia, where the production of magnesia bricks was first carried out on the large scale from the magnesia of Frankenstein, a mixture of dead-burnt with a small proportion of caustic magnesia, crushed fine by roller-mills, was moulded with magnesium chloride solution into bricks which were subjected to a pressure of 110 atmospheres, so that the pressure upon an ordinary brick amounted to 50 tons. After eight days' careful drying in the air, they were placed in the chambers of a Mendheim annular gas-kiln in piles only six or seven bricks high, and subjected to a very high temperature; the firing being controlled by pyrometric cones made of felspar and fire-clay. These bricks are said to have contained 98 per cent. of magnesia, but their cost was too great to create any very special demand, and the manufacture has been given up. According to Lezius the average composition of magnesia bricks in use is about—magnesia 80·9, silica 4·8, alumina 1·6, ferric oxide 6·8, lime 6·5 per cent. When a magnesia brick is laid upon a fire-brick bed, no action takes place below about 1,600° Centigrade, but above that point combination takes place with the formation of a fluid grey slag, which rapidly perforates the fire-brick. When a bed of pure alumina is used the resistance is somewhat greater but not much. The resistance to slagging from the ash of fuel is only about one-half that of a good fire-clay brick. Upon a coke or gas-carbon bed, pure magnesia may be heated higher than the melting-point of platinum without showing the slightest sign of fusion, but in the presence of other substances, fusible combinations are more or less readily formed. The fluxing power of these substances is as follows in ascending order: alumina, lime, ferric oxide, silica and phosphoric acid, the latter substance being far more corrosive in effect than silica. A mixture of pure alumina and magnesia in equal parts is infusible at the welding point of malleable iron, but the combination is rendered easy by the presence of a third oxide.

In addition to their principal application in the basic open-hearth furnace and converter, magnesia bricks have been successfully used for lining kilns for cement-making and in burning

strontia for sugar works, and also in lead and antimony smelting works, as they remain perfectly tight when exposed to molten lead, which readily permeates ordinary fire-bricks.

H. B.

On the Compactness of Hydraulic Mortars. By — Teret.

(Annales des Ponts et Chaussées, July, 1892, p. 5.)

The experiments detailed in this Paper were carried out at the Boulogne laboratory of the Administration des Ponts et Chaussées, of which the Author is principal. The results are given in numerous tables and diagrams. The influence of various conditions on the quality of mortars was investigated, especially variations of quality and quantity as regards the sand used and the proportion of water. The quality of the cement itself did not form the subject of investigation.

The term sand is applied to all particles passing through a sieve with meshes, the sides of which measure 0·157 inch (4 millimetres), all coarser material is termed gravel. A sharp sand was obtained by grinding Cherbourg quartzite, and was then classified by means of sieves of different degrees of fineness. In order to facilitate the classification of natural sands, the Author has adopted three standard types, and refers all sands under investigation to these. In making mortar with sand and cement, the former material is usually measured, and the latter weighed. In measuring sand, however, various causes may produce considerable variations in the results. Moisture, for instance, diminishes the quantity of sand in a given space to such an extent that in a case quoted by the Author, the proportion of sand moistened with 2 per cent. of water was 20 per cent. less in a cubic metre than when the same sand was measured dry. A table is given showing the alterations in the composition of cement mortars due to these variations in the moisture present in the sand. Mortar made in winter is usually richer than in summer. The presence of a large quantity of water causes the sand to pack almost as well as when quite dry. This is especially the case with fine-grained varieties. The variations in the weight of a given bulk of sand also depend to a great extent upon the size of the grains, or, as it is termed by the Author, the "granulometric" composition of the sand. The irregularities due to the measuring of cement are well known, and it is recommended to mix the cement by weight in all cases. In mixing the mortar both cement and sand should first be mixed dry and afterwards wet in a mortar mill, by which means the greatest density is obtained. The proportion of water to be added in the preparation of a mortar necessarily varies with the size of grain of the sand, and the percentage of cement. The best proportion is that which gives the most plastic mortar. The quantity of

water diminishes in proportion as the mortar becomes poorer in cement. A large number of experiments were made with the three varieties of sand chosen as types mixed with a Portland cement in the proportion of 3 to 1 by weight. The results are given in tables and diagrams, from which it appears that even in the densest mortar interstices always remain, amounting to at least 3 per cent. of the apparent volume of the mortar. The nature of the cement is considered by the Author to have little influence on the compactness of a mortar. As regards the proportion of water the Author found that mortar rather drier than the normal consistency was the most dense; but this is only the case when the gauging is very perfect, and on the large scale it is recommended to make the mortar sufficiently plastic for convenient use. In a series of experiments with sands composed of grains of different shapes, it was found that those of rounded form gave the most compact mixture. Mortars immersed in water increase in weight; first rapidly, afterwards more slowly. When exposed to the air the weight first diminishes, then gradually increases. In some experiments with cubes of neat cement, the sides of which measured 2·756 inches (7 centimetres) the increase of weight was found to be 6 per cent. after two years' immersion in sea-water. With smaller masses, such as briquettes for testing the tensile strength, the augmentation in the same time was about 10 per cent. The weight increases in salt water to a greater extent than in fresh. The proportion of water retained in a mortar after drying was found not to be proportional to the percentage of cement, but was also influenced by the nature of the sand. The quantity of water used in gauging also affected the amount retained.

The Author discusses the action of sea-water upon cement mortar and gives analyses, from which it appears that in two stalagmitic excrescences which were formed on the surface of concrete immersed in the sea, the percentage of magnesia was about 30. A number of experiments were undertaken to throw light upon the variation of permeability in one and the same mortar, the action of the infiltrating liquid, the influence of the nature of the aggregate, of the proportion of cement, the composition of the sand, and various other points.

A number of tensile tests were made with mortars composed of a great variety of substances mixed with cement. The highest result was obtained, after the lapse of one year, with a variety of marble. The Author gives a formula for determining the proportions of materials to be used in any case in order to produce the best mortar possible.

W. F. R.

Buildings for Colonies. By — Bernard and — Labussière.

(Le Génie Civil, vol. xxii., 1892, p. 21.)

The colonial administration of France has prepared a series of types of colonial buildings for governors' residences, hospitals, prisons, &c. These have been approved, and have now for some time been made use of. The special conditions governing the design are principally those of a want of skilled labour, and often of suitable materials at the site of the buildings, the requirement for protection against tropical heat, and the rapid destruction of wood by insects, such as the white ant.

The system of construction adopted is to make the main framework of the building, carrying the roof, of iron, and to fill in between the columns with double walls of brick. The outer wall is 4½ inches thick, and the inner 9 inches. The space between the walls is 20 inches, and is readily accessible for cleaning, so as to prevent it from becoming a home for snakes and insects. It is open to the air at the top and bottom, so as to secure good ventilation.

The roof is of corrugated iron, on iron rafters and principals, with an inner roof of plaster.

The floors are on iron joists, and are made by setting tee-bar secondary joists transversely to the main joists at 20 inches apart. Through the tee-bars are threaded a series of iron wires, forming a network of 4-inch squares. This network of iron wire is embedded in and binds together the concrete forming the floor itself.

The partition-walls stop short several feet below the ceiling for better ventilation.

The rooms are 11 feet 6 inches to 13 feet in height. Verandahs about 10 feet wide are carried along both faces of the building. The buildings are raised 5 or 6 feet above the ground.

C. F. F.

Recent Works Constructed in Concrete.

(Deutsche Bauzeitung, 1892, pp. 496, 509, 513.)

The article refers to certain large works in concrete described in the "Deutsche Bauzeitung," in 1888, and then proceeds to describe works carried out during the past three years.

Two concrete bridges over the Flügelweg and the Weisseritz at Dresden.—The enlargement of the Dresden station necessitated the removal of the sidings and workshops to the suburb of Friedrichstadt, necessitating an embanked approach from 17 to 22 yards in height with bridges over the street Flügelweg and the River Weisseritz.

The estimates showed that the bridges would be most cheaply

constructed as concrete arches, and this was decided upon. The main dimensions and characteristics of the arches, both of which are upon the skew, and both surcharged with from 15 to 20 feet of embankment, are as follows :—

Bridge over the Flügelweg.

Angle of skew	18°	25′
	Feet.	Inches.
Length	142	0
Span on square	55	9
Height from road to soffit	30	6
Height from road to springing	6	7
Radius of intrados at crown	20	6
„ „ „ springing	52	0
Radius of extrados at crown	27	11
„ „ „ springing	54	6
Thickness of arch at crown	3	3
„ „ „ springing	6	6
Thickness at footings	14	0

The face of the abutment downwards from the springing of the arch is vertical, while the back slopes rapidly back, continuing the line of the extrados of the arch, the thickness increasing from 6 feet 6 inches at the springing to 14 feet at the footings.

The greatest strain in any part of the arch is a pressure of 186 lbs. per square inch, and the pressure on the foundation, which consists of clayey limestone, is about 10 tons per square foot.

The filling at the back of and over the arch was carried out with great care, and was brought up equally on both sides in level layers. The construction of the arch, wing-walls, and parapets, which required about 5,230 cubic yards of concrete, took about twelve weeks, and cost £5,400 exclusive of all earthwork.

Bridge over the River Weisseritz.

Angle of skew	30°	(about)
	Feet.	Inches.
Length	141	0
Span on square	59	0
Height from river bed to soffit	39	0
„ „ „ springing	2	3
Greatest depth of water	11	8
Versed sine of paved invert	2	3
Radius of intrados at crown	20	6
„ extrados at crown	28	1
„ intrados at springing	37	5
„ extrados „	54	6
Thickness of arch at crown	3	5
„ „ 14 feet above springing	7	0
„ „ at footings	18	0

The arch springs directly from the footing.

The greatest compressive strain on any part of the arch is 242 lbs. per square inch, and the weight upon the foundations

nearly 10 tons per square foot. The cost of this bridge, which required 7,850 cubic yards of concrete, was £8,350.

The concrete was composed of:

—	In the Parapet and Wing-Walls.	In the Arch.
Cement	1	1
Sand	7	6
Broken stone	9	8

The same proportions were used in the concrete for the wells of gasholders at Dresden and Düsseldorf. The former is 140 feet internal diameter and 30 feet deep. The concrete work (exclusive of all earthwork) cost £7,420.

Road bridge at Erbach in Wurttemberg.—The main arch of the bridge has a span of 105 feet, and a rise of only 13 feet 1 inch. To avoid the risk of cracks in the arch on the striking of the centres, flat asphalt joints are introduced into it, one at each springing and one at the crown. The arch is thus divided into two segments by these joints. The joints are made up of several layers, and are at the extrados 0·86 inch, and at the intrados 0·59 inch thick when put in. On the striking of the centres the joints assumed a uniform thickness of 0·51 inch, corresponding with a drop of the crown of the arch of 0·2 inch. Later on, when the roadway was laid over the arch, the settlement increased to 0·47 inch.

The thickness of the arch at the crown is 20 inches, at the springing 2 feet 3½ inches. The thickness of the abutments at the footings, which are 8 feet 3 inches below low-water level of the river over which the bridge is built, is 10 feet 6 inches. The load on the haunches of the main arch is lessened by the construction of spandrel arches.

The greatest compression strain upon the arch is 426 lbs. per square inch, and the cement used had a tensile strength of 227 to 262 lbs. per square inch after seven days, and 312 to 340 lbs. per square inch after twenty-eight days.

The proportions of the ingredients of the concrete were, for the abutments—

Cement	1
Sand	2
Gravel	6
Stones, from 25 to 40 lbs. weight	¼

For the haunches of the arch—

Cement	1
Sand	1¼
Gravel	5 to 4

For the crown of the arch—

Cement	1
Sand	1
Gravel	3

The gravel was river-gravel carefully washed, with no stones less in size than a walnut and none bigger than a hen's egg. The only thing done to make the exposed faces of the arch smooth was to use somewhat finer gravel towards the outside. The concrete was rammed in layers 2 feet 2 inches in thickness.

W. B. W.

Construction of the Boucicaut Bridge. By — Tourtay.

(Annales des Ponts et Chaussées, October, 1892, p. 445.)

This is a masonry bridge, carrying a public road over the River Saône, and derives its name from a lady who has defrayed the entire cost of the work. The engineers, however, were lent by the State for the service, in view of its public character.

A masonry bridge was preferred to iron on the ground of appearance, and because the charges for maintenance of an iron bridge would have been heavier, and would have fallen on the very poor parishes of the neighbourhood.

The bridge consists of five equal spans, each with a clear opening of 40 metres (131 feet 3 inches). The bridge has a clear width between parapets of 26 feet 3 inches.

No solid foundation being attainable at any moderate depth, the piers were founded on piles.

The rise of the arches is one-eighth of the span, a somewhat small proportion dictated by the demands of navigation for a wide opening of maximum height, combined with the necessity of not raising the roadway too high. The following Table (see p. 13), given by the Author as including all masonry arches having a span and a radius of curvature of intrados not less than that of the present bridge, is of interest.

The curve adopted both for the intrados and extrados of the arch was the catenary. The Author has published in the "Annales" (April, 1888, and May, 1889) the calculations which have led him to the conclusion that the adoption of this form leads to considerable economy in the masonry. The mean pressure at the crown is 18·3 tons per square foot. The reduction in pressure that could have been obtained by increasing the thickness was not sufficient to justify any such increase, since the above pressure was considered to afford a safe margin with the class of stone which in any case would have been used.

—	Clear Span.	Rise.	Ratio of Rise to Span.	Radius of Circular Arc of same Rise and Span.	Thickness at Crown.	Remarks.
	Feet.	Feet.		Feet.	Feet.	
Dee Bridge, Chester .	196·7	42·0	$\frac{1}{4\cdot76}$	140·0	4·0	Single span.
Bridge at Claix, River Drac	170·6	26·4	$\frac{1}{6\cdot46}$	150·9	4·9	Do.
Do. at Bains de Lucques	155·9	23·4	$\frac{1}{6\cdot71}$	143·3	5·9	Do.
Do. at Turin, River Dora Riparia	147·6	18·0	$\frac{1}{8\cdot18}$	159·8	4·9	Do.
Do. at Putney, River Thames	144·0	19·3	$\frac{1}{7\cdot46}$	144·0	4·5	Middle arch 144 feet: two of 129 feet span & two of 112 feet.
Boucicaut Bridge, River Saône	131·2	16·4	$\frac{1}{8}$	139·4	3·4	Five similar spans.

The variation in curvature is insensible to the eye, although the vertical distance of the catenary from the circle reaches 10 inches.

The piles were driven by a steam pile-driver, having a 24-cwt. monkey, with a drop of 40 inches. There are one hundred and thirty-six piles to each pier, and one hundred and sixty-eight to each abutment. They are of fir, and 14 inches in diameter at the head, driven about 26 feet into a bed previously dredged. The piles being cut off under water, a timber caisson was sunk around them to form a frame for the concrete foundation, which was deposited under water through a wooden funnel, 16 inches square, in successive layers of a minimum thickness of 16 inches.

If the piles carried the whole load, each would support 33 tons. If the load be considered as distributed over the area included by the piles, the pressure per square foot is a little over 3 tons.

Where the masonry pier rests on the concrete the load is nearly 6 tons per square foot.

All the principal masonry is in stone from Villebois, dressed on all faces. It is set in cement-mortar, the arch-joints having a thickness of $\frac{5}{16}$ inch. The voussoirs have a uniform thickness (measured on the intrados) of 23·2 inches, and a depth, alternately, of 40·5 and 56·3 inches. The original intention was to make the arch in three rings of 12 to 16 inches each in thickness, but, for convenience of various kinds, larger stones were used, the whole thickness of the voussoir being made alternately in one and two stones.

The centres rested on a timber truss, carried by piles at 26-feet centres transversely.

Some trouble was given by a tendency of the whole staging when loaded to incline bodily, owing to a want of perfect verticality in the piles.

The centres of the first arch were struck when only that and the adjoining arch had their full load, and it did not receive sufficient resistance from its pier. Consequently the deflection amounted to $1\frac{3}{4}$ inch. This undue haste was caused by the necessity of providing for the requirements of navigation.

The other centres were simultaneously struck, and the deflections ranged from 0·43 to 0·71 of an inch.

The cost of the work was as follows:—

	£
Foundations	5,120
Structure	13,920
Ornamental carving	400
Total	£19,440

This gives a cost per lineal foot of £25 2*s.* 7*d.*, and per square foot of 17*s.* 4*d.*

An appendix to the article contains an investigation of the variations of stress in masonry arches produced by different methods of striking the centres, by settlement, and by changes of temperature.

C. F. F.

Bridge over the Gérine at St. Sylvester, Canton Fribourg, Switzerland. By A. Gremaud.

(Schweizerische Bauzeitung, vol. xx., 1892, p. 151.)

This bridge, 13 feet 8 inches wide, carries a macadamized roadway, across the River Gérine, at a height of 52 feet 6 inches above high water. There are three spans; the middle one forms a complete parabolic arch of 146 feet span, and 36 feet 6 inches rise. The side openings are of similar arc, but have a length of 123 feet 9 inches only, the arches being unsymmetrical by reason of their abutments being on the slope of a rock at a higher level than the piers. The type of construction is that of a flexible arch stiffened by a lattice girder above the crown but below the roadway. The cross section of the bridge shows two girders, 13 feet $1\frac{1}{2}$ inch apart and vertical, while the two arches beneath them lie in inclined planes, the distance apart of which is 13 feet $1\frac{1}{2}$ inch at the crown, and 19 feet 8 inches near the top of the masonry piers. The cross section of the arched member, which is polygonal according to the panels of 10 feet width, is tee-shaped, consisting near the crown of a web-plate 12 inches by $\frac{3}{8}$ inch, two $3\frac{1}{4}$-inch angle-bars, a flange-plate 14 inches by $\frac{3}{8}$ inch, and an angle-bar $3\frac{1}{2}$ inches by $2\frac{1}{2}$ inches at the edge of the web-plate.

The calculation was made according to Professor W. Ritter's theory, published in the Schweizerische Bauzeitung, 1883, vol. i., p. 6. The total weight of the metal parts is 135 tons, and the total cost, including masonry, £4,347. The ironwork was carried out by Messrs. Probst, Chappuis and Wolf, of Berne.

M. A. E.

Experimental Researches on the Deformation of Metallic Bridges.

By — Rabut.

(Le Génie Civil, vol. xxii., 1892, p. 88.)

The observations here described were made on riveted bridges on the line from Vire to Saint Lô, and consisted in measurements of deflection, rotation of members, linear expansion or contraction, and in autographic records of movement under rolling loads.

For deflections a telescope was used, pivoted to the bridge at one point and to a fixed bearing at another. The telescope read on a staff placed at a distance which multiplied the deflections by 200.

Rotations were observed in three planes by a telescope fixed to the piece under examination. The linear changes were observed by an apparatus modified from that of Manet, in order to procure greater certainty and sensitiveness. It consists of a bar, of which one end is fixed to the piece under examination, and the other actuates the short arm of a multiplying lever pivoted on the same piece at a fixed distance. The various details of construction necessary to secure accuracy are described. The multiplication used in this case was three hundred times. The dial of the instrument is graduated in kilograms by means of a standard dynamometer, and can be read to the tenth of a kilogram.

Autographic records were obtained by means of a lever multiplying apparatus, the record being made on paper wrapped round a cylinder turning with uniform speed, and furnished with an electric chronograph, by which the position of the train for any point on the diagram could be marked. Three cylinders were used, of which one made a complete revolution in twenty-four hours, the second in thirteen minutes, the third in forty seconds.

The conclusions arrived at by the Author from these experiments are as follows :—

Main girders.—During and after the passage of a train at low speed vibrations take place, whose period is independent of the train and of its speed, and is a function of the dimensions of the bridge itself alone. During the passage of a train at high speed vibrations occur, whose period is a function of the wheel-bases of the vehicles and of the intervals between cross-girders, and whose amplitude increases with the speed. In large spans this amplitude is only a small fraction of the static deflection.

The deflections and linear deformations are sensibly different from those arrived at by the usual formulas, based on the hypothesis of frictionless hinges at the joints.

The stresses in the web members are heavier than the usual calculations indicate, the verticals being, as a rule, as heavily strained as the diagonals. This arises from the invariability of the angles between the members of the truss, the effect of which is to produce bending moments at the ends of each member. The stresses thus caused (which, the Author thinks, are improperly termed secondary) are sometimes greater than the calculated stresses, and may thus reverse the sign of the stress in some parts of the member. They increase in magnitude from the ends to the middle of the span; and, for this reason, the Author thinks it unwise to reduce the section of web-members in the middle panels so much as is often done.

Cross-girders and trimmers.—The fixture of the ends of cross-girders to the main girders reduces the stress, but increases the deflection of the cross-girders; but the connection of trimmers to cross-girders reduces both stress and deflection for the cross-girders. The latter connection increases the deflection, and reduces the stress for the trimmer, whose deflection may reach the double of the calculated amount.

Static and dynamic deflections.—For usual speeds, the dynamic deflection increases with the speed of the train, and with the degree of freedom of the member under examination, and inversely with its mass. Its excess over the static deflection is very small for the main girders of large spans, but greater in the spans next the abutments than in the intermediate spans. It is sensible for cross-girders and for main girders of small spans; it is considerable for trimmers, especially near the abutments.

Joints.—The reaction-couples at the joints increase the stress on the rivets in a proportion greater than that applying to the pieces united.

Skew spans.—The effect of a span being skew is equivalent to a partial fixture of the ends of the main girders. The web-stresses towards the end of the girders are reversed and enormously increased in absolute amount.

The Author would prefer to build skew spans in masonry in many cases for this reason.

C. F. F.

On Repairing Iron Bridges without interruption of Traffic.

By Alois Schneider.

(Zeitschrift des österreichischen Ingenieur- und Architekten-Vereines, 1892, p. 683.)

The work of strengthening iron bridges on the Austrian railway systems, on account of the gradual increase in weight of rolling-stock, has in recent times become a pressing necessity;

and it is equally essential that the work shall, wherever practicable, be carried out without interference with the ordinary traffic. So long, however, as the bridge is standing in its free and normal loaded condition, it is evident that the new and old members of the girders must be very unequally loaded; in some parts the strain will be much diminished, in others substantially increased. The erection of a staging to carry the weight not only of the bridge but of the moving load, *i.e.*, to relieve the permanent structure of all strain, would, of course, enable the work to be carried out under the most favourable conditions possible; but the expense of such a process would effectively prevent its adoption.

The Author describes an arrangement, involving the erection of scaffolds at convenient fixed points only, by which the normal strains are counteracted and the structure placed temporarily in a neutral condition. The principle of the process is that by the adoption of a suitably proportioned lever, the fulcrum of which bears on the scaffold or staging, the dead load of the superstructure can be raised so that any temporary weakening of that point may be effected, and any member (*e.g.*, diagonal bars) removed and replaced without dislocation of the structure.

Several bridges have been dealt with in this manner: the first one carried out being of 115 feet span, over the Biala, on the Bielitz-Saybusch section of the Emperor Ferdinand Northern Railway. Each counterstraining lever consisted of an ordinary flanged rail, and the load of similar rail-lengths laid transversely at the requisite distance on the long arm. The vertical upward application of the power to the main girder was effected by a steel shoe, between the cheeks or side-plates of which the rail-lever was passed. This shoe formed, in side elevation, a double bend, the horizontal member (*i.e.*, the short arm of lever) being 10 inches in length, the downward bend (fulcrum) terminating in a knife-edge working in a groove in a bearing plate 9½ inches by 8 inches by 1¾ inch; the upward bend being similarly shaped and bearing on a plate wedged up against the underside of the main girder. The levers were loaded sufficiently to raise the main girders at the centre of span to the extent of about ⅜ inch. The movements of the lever under passing trains were slight and quite steady, and the work was satisfactorily tested upon its completion.

P. W. B.

A Railroad Bridge of Old Rails. By Eduardo J. Chibas.

(The Railroad Gazette, New York, 1892, p. 961.)

The Author describes a bridge built of old 60-feet rails at the Soledad Sugar Estates near Guantañamo, in Cuba, of the Howe truss variety with inclined end-posts, which with both chords are built up of two rails placed side by side, but far enough apart to

admit the braces of single rails to pass between, the vertical tie-rods of round iron being placed outside the chords to which they transmit stress by means of a piece laid transversely outside the chord, and through which each tie-rod passes. The floor beams also are a pair of rails, and the various junctions of the chords, and the inter-sections of the braces are formed by specially cast joint-pieces. These constituted the chief expense and difficulty in the whole bridge, which in all is 392 feet long, made up of two spans of 16 feet, eight of 36 feet, and one of 72 feet. All the parts were prepared at the railway shop at Guantañamo in 1888, the trestles supporting the bridge, which are from 15 to 30 feet high, being also built from old rails, which are of the flanged section. Illustrations accompany the article.

W. H. B.

Construction of an Iron Coal-Pier at Norfolk, Virginia, U.S.

By W. W. Coe, M. Am. Soc. C.E.

(Transactions of the American Society of Civil Engineers, August 1892, p. 125.)

The pier, whose construction is here described, is situated at Lambert's Point, Norfolk, and extends for a length of 805 feet, carrying two elevated lines of railways for loaded coal-cars, one on each side of the pier, and between them a central return line for the empty cars. The two outer lines are laid on a falling gradient of 9 inches per 100 feet, while the return line has a gradient in the opposite direction of 2 feet 6 inches per 100 feet descending to the level of certain yard tracks at the shore end of the pier. At the outer end the return line is connected to each of the side lines by a traversing table, having a transverse motion of 8 feet, with a fall of 8 inches corresponding to the difference of level at this point between the outer and the central track. The traversing tables are so counterbalanced that they come to rest in the line of the outer or delivering tracks and on the same grade. After receiving the empty cars, they move by gravity to the line and to the grade of the return track, and allow the cars to leave the table without assistance. When thus relieved of the weight of the car, the table is brought back by the counterbalance to the line of the delivering track. By this system the loaded cars, after being placed by an engine beyond the summit of the gradient, are henceforth controlled by gravity, and after discharging their load, the empties are formed into a train at the foot of the return line.

The structure is supported upon bents or trestles placed 36 feet apart in the line of the pier, while each trestle consists of four iron piles surmounted by vertical posts of wrought-iron which are united by diagonal bracing. The piles vary from 45 to 57 feet in length, and consist of wrought-iron pipes 12 inches in diameter and $\frac{1}{2}$ inch thick, made in lengths of 14 to 20 feet, with flush joints, and with a cast-iron disk 4 feet in diameter at the base of

each pile. Below the transverse bracing of the vertical standards, a second system of bracing unites the heads of the four piles in each trestle. This consists of a pair of frames flanking the piles on each side, each frame being formed of two transverse bars of 12-inch channel-bar with a vertical distance of 12 feet between them, and united by cross-bracing of angle-bar. Between these frames the four piles are held in semi-circular clamps bolted to the channel-bars, the clamps serving first as guides for the sinking of the piles, and afterwards as a permanent attachment, gripping the pile tightly when screwed up. For the protection of the iron structure rows of creosoted timber piles were driven, extending laterally 8 feet beyond the iron pier on each side, and forming a low-level landing-stage.

In the execution of the work, this timber outwork was first constructed, and served as a staging for the sinking of the iron piles, which were carried down through an easily penetrable sandy marl until a somewhat firmer substance was reached. The sinking was effected by a water-jet at a pressure of 36 to 60 lbs. per square inch, the water being delivered into the interior of the hollow pile at this pressure through a water-tight cap, and directed partly in a vertical stream through a central nozzle $1\frac{3}{8}$ inch in diameter under the centre of the disk, and partly in nine radial lines with a vertical inclination of 45° through nozzles $\frac{3}{8}$ inch in diameter.

For the execution of the work a traveller of about 50 feet span was constructed, running upon the timber low-level stage and having a clear height sufficient to embrace the whole superstructure of the pier. The traveller was composed of two Howe trusses supported by double posts on each side, firmly braced together and resting on large truck frames. It carried a boiler of 50 HP., supplying steam to a hoisting-engine on one side, and, on the other, to a Worthington duplex pump which supplied the water-jet.

The four piles constituting a trestle were first placed by the traveller in accurate position, and the sub-system of braced framework was attached. This served as a guide for each pile in succession, and on applying the water-jet the weight of the pile was generally found sufficient to carry it down about 6 feet. At this point the sinking had to be assisted by increasing the load, which was done by applying a downward pull of about 36 tons upon the head by means of the hoisting-engine, and with the action of the jet this was sufficient to carry the pile down to the firmer substratum. A test load of 64 tons was then brought on, and invariably caused the pile to sink deeper, owing to the previous disturbance of the sand by the water-jet. But when a certain settlement (averaging 13 inches) had taken place, the test load produced no further subsidence when allowed to remain for four hours on the pile. After this had been ascertained, the pile was cut off at the proper height and filled with concrete, and the clamping bolts of the sub-bracing having been then tightened up the substructure of the trestle was completed. T. C. F.

Block-Setting Crane at Ponta-Delgada, Azores.

By Al. Lévesque.

(Le Génie Civil, vol. xxii., 1892, p. 129.)

This crane is being used in the construction of a mole of concrete blocks on a rubble foundation at the abovenamed port.

The heaviest blocks weigh 30 tons, and can be set at a distance of 98·4 feet from the axis of rotation of the crane. Blocks of 15 tons can be set at a radius of 147·6 feet, and blocks of 12 tons at 164 feet. The blocks are lifted by chains passed round them, two grooves being left in each block for the purpose.

The turning part of the crane very much resembles a triangulated girder swing-bridge, as commonly used for dock-entrances. The depth of the girders is 19·7 feet over the supports, and diminishes to 11·1 feet at the outer end. The tail end is 91·9 feet long, and carries a counterweight of 113 tons of masonry.

The girders have vertical posts and diagonal tension-bars, and are spaced at a distance apart of 7·2 feet. The carriage travels on ways near to the lower flanges of the girders, so as to admit of transverse bracing between the girders throughout. These ways are at a distance apart of 4·6 feet.

The crane can turn through a complete circle, and turns on a live ring of rollers of 26·2 feet diameter.

The live ring rests on the head of a square-framed iron pier, the sides of the square being 26·2 feet, and the height from rails to under side of girders 39·4 feet. The legs of the pier are braced together on each face; but transversely to the railway the bracing only commences 16·5 feet above the rails, so as to allow the wagons bringing blocks to enter beneath the crane.

The pier rests on the rails laid along the mole by means of four four-wheeled trucks, the wheels being of 3 feet diameter; and provision is made that, in case of an axle breaking or any similar accident, the load will immediately be taken by shoes, which travel very close to the rails. The load is distributed by levers evenly between the wheels.

All the movements are derived from a steam-engine of about 65 HP.; and the movements of translation and rotation of the crane can also be produced by hand-power. Two of the wheels on each truck are driving-wheels. Chain-gearing is used for transmitting all the motions.

As there is a curve on the railway, a differential gear is provided for the wheels at one side of the crane, which can be thrown into play when required, and which gives the requisite difference in velocity between the wheels on the inner and outer rails. All the driving-wheels are fast to the axles on the straight, but those on the outer side of the curve are set loose on entering the curve.

Under the worst positions of the load, as regards stability, the centre of gravity of the whole turning-load is 6·6 or 8·2 feet within the live ring.

The crane was designed by Mr. Seyrig, M. Inst. C.E., and built by the Société Franco-Belge at Raismes.

C. F. F.

Port of Karáchi, West Coast of India.

Report by D. Morris, M. Inst. C.E, to the Karáchi Port Trust.[1]

(8vo. Map and Plans. Karáchi, 1892.)

The harbour of Karáchi, 495 miles N.W. of Bombay, was thirty years ago simply a creek running inland with depressions off Manora and Keamari, where vessels of light draught could anchor, and in the south-west monsoon it could neither be entered nor got out of with safety. In 1860 the late Mr. James Walker, Past-President Inst. C.E., proposed, and the government sanctioned, extensive works of improvement, which have been carried out during the past thirty years under the superintendence of Mr. W. H. Price, M. Inst. C.E., with the result that the harbour can now accommodate a large number of steamers, with draught up to 26 feet, and can be entered at all seasons. Its present extent is 232 acres, of which 211½ acres are available as anchorage ground for the largest vessels.

It is essentially a backwater harbour, the entrance and anchorage forming the lower division, the creeks and backwater (18 square miles) constituting the upper division. The principal improvement works consist of:—

1. A breakwater on the western side extending south by east from Manora Point for 500 yards into 5 fathoms of water, which affords shelter to the entrance during the south-west monsoon.

2. On the eastern side a stone groyne, extending for 1·92 mile in a N.N.W. direction from the mouth of the harbour to Keamari Island, which confines the ebbing and flowing currents to the harbour channel.

3. A new entrance channel ½ mile long, at first 500 feet, but now 1,200 feet wide, and 22 feet deep at low water. This channel is still being deepened by blasting and dredging, and will eventually have a minimum depth of 24 feet below low water.

4. The whole of the harbour channel has been deepened and widened from the entrance to the pier and wharves at Keamari, and now averages 700 feet in width and more than 24 feet below low-water level, which depth is maintained by natural scour. In 1890, 564,371 tons of rock, clay, and sand were dredged and removed from the anchorages.

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[1] The original is in the Library Inst. C.E.

5. Another channel has been formed for native boats from Keamari to the native jetty and Napier Mole Boat Wharf, which is 300 feet wide and about 12 feet in depth at low water.

6. The mouth of Chinna Creek has been closed, and the flowing and ebbing waters to and from the eastern backwater are now directed through the harbour, thereby exerting their scouring-power upon the harbour channel and entrance.

7. A rocky ledge, which projected into the harbour channel at Manora Point and throttled and deflected the tidal flow from its proper course, causing eddies and preventing safe anchorage at Manora, has been removed.

8. A lighthouse, 91 feet in height, has been built on Manora Point, at the entrance to the harbour, and a red light has been fixed at the end of the Manora breakwater, which is visible in clear weather at 5 nautical miles distance. Further works of considerable importance are still contemplated.

The effect of these great works has been an addition to the harbour water space of upwards of 250,000,000 cubic feet.

In point of importance, Karáchi (population 104,000) is now the third port in India and is the capital and seat of the provincial government of Sind. It is the natural seaport of Sind, the Punjab, Kashmir, Eastern Baluchistan, Afghanistan, and central Asia; a direct railway to Delhi, now approaching completion, will shorten the distance by rail between Delhi and the seaboard by about 153 miles. It is also the nearest harbour to Europe, being nearer by 205 miles to Aden than Bombay, and by over 400 miles to Bassorah and the head of the Persian Gulf. Eight regular lines of passenger and cargo steamers connect it directly with Europe, and it is also the trooping port for Northern India and the north-west frontier. Cargo is landed and shipped direct into and from railway wagons, which are worked by hydraulic capstans and locomotives.

The imports comprise coal, cotton and woollen manufactures, metals, liquors, machinery, provisions, kerosene and other oils, railway plant, timber, &c.; and the exports consist of raw cotton and wool, hides and skins, indigo, grain and pulse, animal bones, fish, flour, fruits and vegetables, oleaginous seeds, tea, &c. In 1891, 46,757 tons of coal were imported, and 556,595 tons of wheat exported; 475 steamers of 613,350 net tonnage, and 10 sailing vessels of 3,961 net tonnage, entered the port. The total value of the foreign trade amounted in 1890 to 83,113,944 Rs., and of the coasting trade to 40,671,853 Rs.[1]

[1] The value of the rupee has decreased so rapidly during the last few years that it is difficult to give the equivalent of these figures in English money. Formerly the Indian Mint manufactured 10, but now as many as 16 rupees from 20 shillings' worth of silver.

O. C. D. R.

The Illumination of Beacons. By Domenico lo Gatto.

(Giornale del Genio Civile, 1892, p. 429.)

Until quite recently, the only practical methods of coast illumination were lighthouses on headlands or reefs, and lightships on shoals, both entailing considerable cost both in establishment and in maintenance. The development of Pintsch's system of lighting buoys has, however, demonstrated the possibility of the automatic maintenance of lights in isolated localities which may be inaccessible for considerable periods, and has led to the adoption of storage-systems for beacon-lights which have been successfully carried out in several parts of Europe and America. Pintsch, in the former continent, and Foster in the latter, both extracted from heavy mineral-oils gas which could be considerably compressed; though under the one system the pressure is not carried beyond 11 atmospheres, while the other is forced to as much as 40 atmospheres. The essential parts of beacons lighted on this compressed gas system are: the gas reservoir, pressure regulator, jets, and lantern apparatus. It is now usual to keep the light permanently burning, in preference to any regulation by clockwork.

An ordinary pile structure is all that is required, and is, indeed, preferable in most cases to a solid erection presenting a greater surface of obstruction.

In a beacon constructed for the Torrione shoal in the Procida Canal, the capacity of the accumulator is 285 cubic feet, and this, when charged at a pressure of 7 atmospheres, will give a light lasting eighty days. In the Suez Canal beacons the accumulators are double this size. A high luminous intensity can be obtained by this system; for a fifth order apparatus with burner for 27½ gallons per hour, and for a white light, would be equivalent to 1,330 candles, and would in clear weather be visible at a distance of 26 miles. Such intensity is, however, not required for the purposes of ordinary beacons, which do not require to command such a radius. To maintain a steady light in continuous service the pressure must not sink below 1½ to 2 atmospheres, and occasional attention must be given to cleansing the lantern apparatus and clearing the tube and burner. Most of the beacons erected for Pintsch's light are (as in the Suez Canal) in calm water and unexposed situations.

Spirit of petroleum, or Lythene—which vaporizes rapidly above 86° Fahrenheit—is the illuminant employed in the system introduced by Mr. Lyth, the Engineer to the Corporation of Swedish Lighthouses. For the combustion of this vapour all mechanism is eliminated, the burner consisting of a bronze "spreader," the upper edge of which serves also as a deflector. The spirit rising and impinging on the surface of the metal is (after light has once been applied) immediately vaporized, and forms a brilliant illuminant. It is essential that the reservoir should be at a sufficient height above the level of the jets, and that—except for a land-

beacon—it should not obstruct the focal-plane of light. The oil is passed from the reservoir through a small regulating chamber by which the liquid is maintained at a constant level, and rises in sufficiently small quantities to maintain a fixed rate of vaporization. It is generally also filtered through wire-gauze. The burners can be grouped in two or in four, the former being sufficient for an ordinary white light of 16 candle-power, the consumption of oil for this light being 0·7 gallon per twenty-four hours. In the light on the east pier at Genoa the consumption is 1 gallon per twenty-four hours; but within either of these limits a light of long duration can be obtained without an excessive size of reservoir. The oil should be the purest degree obtainable, and may then burn as long as five months without being touched; but impurities cause considerable carbon deposits on the burner and clog the gauze, so that it would require fortnightly visits to attend to cleansing and renewal.

The chief development of this system has been in Sweden, Norway, and Finland, where it is extensively employed in the fjords. In Sweden alone, some time since, the number of lights was over one hundred and fifty. The French Government have erected one light, on the Lavardin shoal, near the island of Ré, and have ordered two others; and the Trinity House have two in the estuary of the Thames—one Pintsch light and one Lyth-Lindberg. The Lavardin light is in an isolated and exposed situation, and the reservoir has a capacity of 100 gallons, feeding four burners, and capable of maintaining a steady light for three months without attention. The cost of this light (apart from the structural work) was £280.

The Lyth light received a great development by the addition of Lindberg's flashing apparatus, by which a distinctive character is obtainable. The set of screens is fixed in an inclined position on a frame resting on a steel pivot in an agate cup fixed over the light, and is set in motion by the hot air rising from the burners. This process is much facilitated if the lantern is surmounted by a chimney of a certain height, to intensify the updraught. Although the revolution of the screens is not so perfectly uniform as by clockwork, it proceeds unceasingly from the moment the light is started, and none of these flashing lights have yet failed on any occasion. At Genoa the screens made 6 revolutions per minute in calm weather, and 8 revolutions in a high wind.

The renewal of the combustible is an easy process, as, even for the three months' light, requiring 100 gallons, the oil can be brought in an ordinary boat in small cans easily manipulated. The Pintsch light requires a specially constructed sailing vessel for the accumulators, or a tug. The cost of maintenance of the Lyth-Lindberg light at Genoa is about 5*s*. per twenty-four hours. The apparatus itself—including lantern 24 inches diameter, two external reservoirs, double spreaders, apparatus of sixth order (to light full 360°), and flashing apparatus—costs about £200. No average price can be stated for the pile framing or other sub-

structure, as this necessarily varies with each case. The essential requisites of a beacon light are: reliability of automatic working, long duration of light, and safety, simplicity, and facility of maintenance.

In illuminating power the Pintsch system has undoubtedly the greater capacity, and is therefore preferable for coloured lights or long distances. For white lights of ordinary power both are fairly equal.

In automatic working both are equally efficient, but the Pintsch apparatus is the more complicated.

In duration of light the Pintsch is superior, as periods of four to five months can be attained, while the Lyth system has its apparent limit at about three months, and is generally worked at far shorter periods.

In simplicity of maintenance the Lyth system is unquestionably preferable.

Summarizing generally, the Author considers that the Lyth-Lindberg light most satisfactorily fulfils all requirements for isolated beacons of moderate power and fairly limited range.

A description is also given of an electric beacon at Las Puercas; but the Author does not consider that the system has been sufficiently tried to enable a definite opinion to be expressed as to the solution of the problem.

P. W. B.

On Considère's Formula for the Terms of Leases of Branch Lines of Railway. By — Colson.

(Annales des Ponts et Chaussées, November, 1892, p. 561.)

There has been recently much investigation devoted in France to the determination of a satisfactory general settlement of the terms on which branch railways constructed by, or with the assistance of, the State, should be leased to private persons.

In the "Annales des Ponts et Chaussées" for February and March 1892, a new formula was put forward by Mr. Considère, which the present Author considers to be the best practical solution of the question yet offered. He differs, however, very much from Mr. Considère on the arguments by which that formula was supported, and considers that those arguments, if generally accepted, would lead to the construction of many lines, which would be unproductive if rightly regarded.

The points of difference are mainly as follows:—

(1) The Author thinks that Mr. Considère very much exaggerates the value of the traffic which new branch lines contribute to the main lines, in estimating it, on the average, at 140 per cent. of the traffic of the branch itself.

(2) He also thinks that the direct gains of the public by railway

transport are under-estimated by Mr. Considère as regards main lines, but much over-estimated as regards branch lines.

(3) He considers also that the indirect gains to the public from new branch railways, which Mr. Considère rates very highly, are not of any great importance.

The Author's conclusion is that, in general, a new branch line will not be a source of increased wealth to the country at large, except where its gross receipts are somewhat more than half its working expenses, including interest on capital.

A chapter is devoted to the question of tariffs, on which Mr. Considère's views of the indirect benefit to the public of railway transport lead him to advocate extreme reductions. Mr. Considère's principles would abolish all classifications not founded on cost of working, and would justify railways in working at a loss, to be made good to them by the State.

The Author combats these views and adheres to the doctrine of Dupuit, his arguments on this point being scarcely capable of abbreviation.

These objections, however, do not apply to the formula itself which the Author considers to reconcile in a satisfactory way the interest of the State, that of the lessee, and that of the public.

It is as follows :—

$$F = a + b R_v + c R_m + d V_k + e M_k + f K,$$

where F is the annual share in francs of the receipts per kilometre allotted to the lessee, a, b, c, d, e, and f are constants, R_v and R_m are the gross receipts from passengers and goods respectively, V_k is the number of passenger-kilometres, M_k is the number of ton-kilometres, K is the number of train-kilometres.

The Author would simplify this by making $d = o$, and increasing b a little in compensation. Since b is only little less than c, b and c may now be made equal, and the formula becomes

$F = a + b R + e M + f K$, where R is the gross receipts in francs.

He recommends the values $a = 300$, $b = 0{\cdot}5$, $e = 0{\cdot}005$, $f = 0{\cdot}3$.

In constructing a new branch the lessee should furnish, by way of guarantee, a small share of the capital, and the interest on this be added to the value of F above.

The main line ought to bear the cost incurred at the junction, and in some cases may fairly be called on for a subvention as well.

If a lessee cannot be found on these terms, then the line is one which it is not the interest of the State to build.

C. F. F.

New System of Washing Ballast, Employed by the Northern of France Railway Company.

By Alfred Hauet.

(Revue générale des Chemins de fer, 1893, p. 95.)

This article describes a new system adopted for washing stones for railway-ballast. It is pointed out that the former favourable opinion of a binding earthy or sandy ballast has been considerably modified, and that now a ballast entirely freed from earthy or friable material is regarded, at any rate by permanent-way engineers, as greatly to be preferred. From this conviction has originated a new method of treating deposits of ballast, of which the herein described installation is considered as occupying the most advanced position, especially as the deposit operated upon does not merely contain sand and stones easy of separation.

For the ballasting of the Laon and Liart line, none of the old systems could be adopted, for the principal reason that the only neighbouring deposit of ballast, at Grondrieux, the treatment of which is here described, consisted of a damp and pasty mixture forming a natural mortar or cement, which defied the ordinary methods of washing.

The deposit is estimated to contain in round numbers 3,500,000 cubic feet, or somewhat more perhaps than the amount required for ballasting the line.

The extraction is effected by Boulet excavators loading into trucks of 1 metre gauge, holding about 8 cubic yards. A set of 12 trucks is filled in fifteen minutes, and is taken by a 10-ton locomotive down to a branch line B, another set of empty trucks being brought back. A second similar locomotive takes the loaded trucks from B to the washers, where they are discharged by pairs into the hoppers at the ends of the washers. A pump lifting 75,000 gallons of water per hour is installed at a point of the River Serre, and is driven by a 30 HP. engine. The water is forced to a distance of 350 yards, and an elevation of 43 feet above the intake. This water, after being used in the washers, is discharged, laden with earth, sand and small pebbles, through a launder into an existing reservoir or basin containing a superficial area of over 45,000 square yards; thence it passes to a second smaller basin and again to a third, flowing from the latter, in a practically pure condition, back into the river.

The excavator, engines and pump are of the usual types, but it is otherwise with the washers, which constitute the main feature of the system. Four washers work simultaneously in a battery, being driven by a 60-HP. engine. They are connected in parallel, on a raised platform, and set at right angles to the line of rails.

Each washer consists essentially of a revolving shaft somewhat over 20 feet in length, of which 16 feet 6 inches is provided with narrow radial blades. This shaft has an inclination to the

horizontal, capable of adjustment as desired, according to the circumstances and requirements of the case. The steel blades are arranged round the shaft in the form of a helix, the outside diameter being about 2 feet 4 inches; they are provided with steel ends bolted on so as to be easily renewable when worn. Each shaft works in a sheet-iron trough with a cylindrical bottom bored with holes of about $\frac{1}{2}$ inch in diameter, to allow the discharge of the water and the small stones. A free space of 2 inches is left between the ends of the blades and the inner surface of the bottom of the trough.

The raw material is fed into hoppers at the lower end of the troughs and is thoroughly agitated and broken up by the action of the blades. The rotation of the shaft with its helical arrangement of blades drives the stones towards the upper or discharge end of the trough, where they leave the machine perfectly clean and covered only with a film of water. The water for washing is supplied from a distributing pipe fixed longitudinally over the trough. The inclination of the troughs and the holes therein prevent the water passing over with the stones, which fall on an inclined plane and are raked on to a platform alongside the temporary line, ready for loading into the empty trucks.

The working staff consists, besides the contractor's representative, of 4 foremen, 30 men with the excavators, 6 drivers and 6 firemen for the small engines, 2 stokers for the pump-engine, 2 stokers for the washing-machine engine, 20 men unloading into the washers, 10 men on the platforms, 35 men loading into the trucks, and pointsmen, lampmen, and mechanics numbering 26.

The material excavated contains 40 per cent. of sand and clay. The average production is from 6,300 to 7,350 cubic feet per day of 24 hours. Allowing, in calculating depreciation, for a total output of 120,000 cubic yards, it is estimated that the cost does not exceed the price generally paid for ballast washed in the ordinary manner.

A plan of the ground, with positions of the plant, is given, as also sections showing the arrangement of the washers and some details of their construction.

F. E. B.

Graphic Representation of the Velocities and Discharges of a River. By Henri Vandervin.

(Annales des Travaux Publics de Belgique, 1892, p. 123.)

When the velocity of a river is always the same with the same depth at a given point of observation, a sufficient number of observations enables curves to be drawn by which the flow and velocity can immediately be read off, as soon as the depth is known.

With many rivers this is not the case, however; and the purpose of the present Paper is to show how corresponding curves can be drawn by which the velocity and flow of a river whose regime is known can be at once ascertained from observations of the surface velocity between fixed points, and of the depth at a fixed point.

The method applies to the graphic representation of any function of two independent variables x and y, of the form

$$Y = f(x) \times \phi(y).$$

The function $f(x)$ and $\phi(y)$ need not be capable of analytical expression, but may be known simply by a series of values.

The process is to lay down the two curves $f(x)$ and $\phi(y)$, and for the latter curve to draw from a point on the axis of y, at a distance unity from the origin, a pencil of rays representing the angles $\theta = \tan^{-1} \phi(y)$. For each of these rays the ordinate at the origin is the same as that at the corresponding point of the curve $\phi(y)$, which enables them to be drawn immediately when $\phi(y)$ is known.

If the curves of $f(x)$ and $\phi(y)$ be so drawn that the value of $f(x)$ can be read along the axis of (y), and the origin for $f(x)$ is the centre of the pencil of rays spoken of, the value of Y can be ascertained at once by inspection of the diagram when x and y are given since $Y = f(x) \tan \theta$.

To apply this to a river, let x be the depth of water at a given station, and $f(x)$, or Ω, the corresponding mean section of flow; let y be the time occupied by a float in travelling between fixed points of observation, and $\phi(y)$, or u, the mean velocity. Then Q the flow $= \Omega u$, and the above method applies.

The curve of u will be very nearly a hyperbola, since, n being the ratio of mean to surface velocity, $\frac{u t}{n}$ is the constant space traversed, and n is nearly constant (about 0·8). If the channel is trapezoidal, the curve of Ω is a parabola.

Examples of the diagrams are given in the Paper as applied to the gauging of the river Senne.

The use of this method is recommended as saving time and securing accuracy in obtaining discharges, and as capable of being used by persons to whom the necessary calculations from the given elements could not be entrusted.

C. F. F.

The Regulation of the Adige in Tyrol and Italy.

By WEBER VON EBENHOF.

(Zeitschrift des österreichischen Ingenieur- und Architekten-Vereines, 1892, p. 493.)

The Author, in an extended and exhaustive article, describes fully the topographical and geological features of the course of the Adige and its tributaries, and reviews the historical development of the works which have been undertaken from time to time, and more especially within recent years, by the Austrian and Italian governments respectively.[1]

The Adige (German, *Etsch*) has a length of 254 miles, and is an important member of the great system of the Po, which has a gross drainage area of about 26,650 square miles.

The last systematic scheme of improvement works in Austrian territory was authorized in 1886, and comprises a length of nearly 65 miles, viz.:—

	Miles.	Chains.
1. From Passer (near Meran) to below Botzen	17	63
2. From end of previous section to Gmünden	7	26
3. From Gmünden to San Michele	14	30
4. From San Michele to the confluence of the Leno at Sacco (below Roveredo)	25	34
	64	73

Of the above, section 1 has been finished, and the remaining portions were to be completed in 1892. The result has been the effective deepening of the bed, and conspicuous relief of the surface, the level of the water being lowered in some places to the extent of over 6 feet. The crest of the dams is fixed at 2 feet above the highest recorded flood-level, the width at the top being 9 feet 10 inches, and the landward slope $1\frac{1}{2}$ to 1. The river-face slopes at 2 to 1 down to mean water-level, where there is a bend of 1 in 12, the lower slope, faced with stone, being $1\frac{1}{2}$ to 1.

The great range in the volume of water is exemplified by the following figures for various points on the section from San Michele to the frontier:—

	a. Cubic Feet Per Minute.	*b.* Cubic Feet Per Minute.
1. Normal low-water from	105,950 to	243,685
2. Normal high-water from	1,356,160 „	2,485,040
3. Highest recorded flood	2,330,900 „	4,238,000

The proportionate volumes 1, 2 and 3 in columns *a* and *b* respectively are thus—1 : 13, 1 : 22, 1 : 10, 1 : 18·5.

[1] Minutes of Proceedings Inst. C.E., vol. cii. p. 351.

P. W. B.

The Development of German Waterways and the Utilization of Water-Power on the Moselle. By — Schott.

(Zeitschrift des Vereines deutscher Ingenieure, 1892, p. 1321.)

The importance which is attached to the improvement of inland navigation in Germany and the extension of the canal system throughout the empire,[1] is shown by the great development of water-traffic, which, in the decade from 1875 to 1885, increased by 65 per cent., and at the present time amounts to 23 per cent. of the total traffic throughout the country. A connection from the Dortmund and Ems Canal to the Rhine is now projected, but details are not yet settled, as great difficulties exist in the network of railways to be traversed. The re-canalization of the Ruhr for traffic of moderate tonnage, and of the Lahn up to Giessen, are also under consideration. More important still is the formation of a waterway available for vessels of large tonnage from Mannheim on the Rhine to Strasburg, the cost of which is estimated at £500,000; while the canals in this part of the country are to be enlarged and improved, and similarly in the north of Germany. It is also contemplated to deepen the channel of the Rhine as far as Cologne, to give a minimum depth of 16 feet 6 inches.

The canalization of the Moselle and of a short length of the Saar will form a connecting link between the canal systems of France and Germany, and will provide a most important channel for the conveyance of iron and other materials. The annual traffic, over the length of 250 miles, has been closely estimated at 2,000,000 tons. Between Metz and Coblenz the total fall is 330 feet, and this, in 40 locks, gives an average fall of 8 feet 3 inches per lock. The normal dimensions of the locks are: length, 362 feet 6 inches; breadth, 32 feet 9 inches; depth, 8 feet 3 inches. The water required for the series is therefore about 2,800,000 cubic feet, which at the normal level of the river is equivalent to twenty minutes flow of the current. Each lock is constructed at the end of a weir; and, under the above conditions, a turbine, at an effective power of 75 per cent., would develop 2,000 HP., or a total, on the length of the channel, of 80,000 HP. For a great part of the year this power would be increased by 50 per cent.; and by adopting electric transmission of the power thus developed it would not be necessary for factories and works to be established on the river bank, but the power would be conveyed to any required point. The capital value of this power, at its minimum and at its local rate, would be £1,200,000, and the cost of the entire work is estimated at £2,000,000. It is proposed to deal in a similar manner with the Saar, the Lahn, the Lippe, the Ruhr, the Main, and other rivers.

[1] Minutes of Proceedings Inst. C.E., vol. lxxxv. p. 448; vol. lxxxviii. p. 501; vol. xc. p. 492; vol. xciv. p. 332; and vol. xcvii. p. 435.

P. W. B.

Hydraulic Installation for the Supply of the Oise-Aisne Canal.

By Emile Meunier and Léon Feray.

(Annales du Conservatoire des Arts et Métiers, 1891, p. 290, 3 Figs. and 2 Plates.)

The Oise and Aisne canal leaves the canal adjacent to the Oise near Chauny, crosses the Oise by means of an aqueduct, and joins the Aisne canal at Bourg-Comin, after traversing a distance of 29·8 miles, of which nearly 1·7 mile is under ground. As it was impossible to obtain an adequate supply of water for the canal from natural sources, a mechanical system of supply was adopted, for which the necessary works were constructed at Bourg-Comin. At this place the canal parallel with the Aisne is formed by a branch from the latter river, which has a mean fall of 27 feet 10 inches—varying from 19 feet 8 inches to 32 feet 10 inches—in a stretch of 12·43 miles.

Here three distinct groups of machinery for raising water have been erected, each group consisting of one turbine and two pumps. These lift about 53 cubic feet of water per second through a height of about 53 feet 10 inches, into a channel connected with a large storage reservoir. The pumps draw their water from the head-race for the turbines.

Under ordinary conditions, the quantity of water available for driving the turbines ranges from 51·21 to 68·86 cubic feet per second, while the corresponding falls are respectively 32 feet 1·8 inch, and 21 feet.

As this variation in head is due to the rise and fall of the tail-water level—the head-level remaining constant—it was necessary to use draft-tubes in connection with the turbines. Hitherto draft-tubes have only been employed with re-action turbines, to which class belongs the Jonval turbine. The engineer, Mr. Meunier, however, considered that with the variable water-supply in question, the average efficiency of a Jonval turbine would be too low, and therefore devised a novel arrangement of "Girard" (or free-deviation) turbine, with vertical shaft, working by suction with a draft-tube. The level of the water in the draft-tube is kept a little below the wheel by the admission of just sufficient air for the purpose, so that the discharge takes place in a partial vacuum, while the motor runs clear of the water. The admission of air is effected automatically by means of a float connected with a valve. When the float rises above a certain point, the valve opens, and admits air under the turbine.

The turbine is regulated by means of twelve radial slides opening and closing the guide-ports, and actuated by a cam turning about the boss of the guide apparatus or distributor.

Each turbine has a mean diameter of 5 feet 3 inches, forty-eight guide-ports, each with a sectional area of 1·46 inch by 4·32 inches, a speed of about 70 revolutions per minute, and develops about 140 HP. with the mean head of 26 feet 3 inches, and corresponding supply of water, 61·8 cubic feet per second.

From each turbine the power is transmitted to its pump crank-shaft, through a cast-iron bevel-pinion and mortice-wheel, having the speed ratio $\frac{40}{156}$, and the following dimensions:—Diameter of pinion, 3 feet 11·24 inches; number of teeth, 40; diameter of wheel, 15 feet 4·25 inches; number of teeth, 156; pitch of teeth 3·7 inches; breadth, 13·39 inches.

The pumps are of the horizontal double-acting plunger type, with double-seated valves, running at a speed of 18 revolutions per minute. The diameter of plungers is 28·74 inches, and the stroke 39·37 inches. The water is delivered through two pressure-mains 35·43 inches diameter and 3,280 feet 10·6 inches long.

Three auxiliary turbines are employed; one for electric lighting, a second for driving an overhead traveller, while a third works the tools in the repairing shops.

Experiments were undertaken by Messrs. Boeswilwald and Lefort, the engineers of the canal, for the purpose of determining the quantity of water used by the main turbines and delivered by the pumps. In each case a weir of the full width of the channel—without end contractions—was employed, the crest being a thin plate.

For the measurement of the motive-power water-supply the weir was placed in the head-race; its length was 68 feet 10·78 inches, height of crest above the bottom of the canal 14·17 inches, while the head over the weir ranged from 3·94 to 5·19 inches. The coefficient employed in calculating the discharge was that given by Bazin in the "Annales des Ponts et Chaussées" for October, 1888, p. 446, and had the value 0·444.

The following are some of the leading results selected from the Table given in the original:—

	Group of Two Turbines.	Group of Three Turbines.
Duration of experiment, minutes	840	360
Number of guide-ports open	24	36
Mean number of revolutions of each turbine per minute	16·95	16·4
H = Available head, feet	20·735	20·669
H′ = Lift for pumps, feet	54·527	54·790
Head over weir in supply conduit, inches	9·37	11·69
V′ = Volume of water raised per second, cubic feet	33·016	46·974
V = ,, ,, supplied to motors per second	140·737	210·766
V H = Available work, foot-lbs.	182,163	271,961
V′ H′ = Useful work, ,,	112,401	161,802
$\frac{V' H'}{V H}$ = Efficiency	0·616	0·594
Coefficient of discharge of pumps	0·9967	0·986
Loss of head in pressure-mains, feet	1·978	4·067
Gross lift of pumps (including loss)	56·505	58·857
Effective work, foot-lbs.	116,473	172,579
Gross efficiency	0·639	0·634

The quantity of water delivered by the pumps was gauged in a similar manner in the supply-conduit, near the discharge orifices of the pressure-mains. The length of the weir was 13 feet 1·48 inch, the height of the crest above the bottom of the conduit 16·54 inches, and the value of the coefficient adopted 0·442. The head for the turbines and the lift of the pumps were both carefully measured; also the number of revolutions made by the former. The leakage from the head-race and reservoir connected with it, and from the supply-channel, were ascertained by trials.

The efficiency of the main turbines themselves, as measured from the power given off by the horizontal pump-shafts, and therefore including the loss from friction of the gearing, the Author estimates at from 75 to 76 per cent., allowing 80 per cent. for the efficiency of the pumps.

G. R. B.

The New Hydraulic Works at Niagara Falls.

(The Iron Age, New York, Dec. 8, 1892, p. 1106. Plate and Cuts.)

In a brief historical sketch of the Niagara utilization scheme, and a general description of the undertaking, there is included a description of the turbines which are to be employed, and which will be each of 5,000 HP. Two are being constructed by J. P. Morris and Co., of Philadelphia, from the designs of Faesch and Piccard, of Geneva, to work under an average head of 136 feet at a speed of 250 revolutions per minute, and to consume 430 cubic feet of water per second, for which purpose the diameter of the receiving circumference is 5 feet 3 inches, and there are 32 vanes divided into three tiers by division-rings, corresponding with similar divisions in the guide-blades, of which there are 36, the united depth of the three tiers being about 10 inches, exclusive of the thickness of the division-rings, about 1 inch each. The shortest distance between any two of the wheel blades is $1\frac{1}{4}$ inch. Each wheel is really made up of two quite distinct Fourneyron turbines fixed on the same vertical shaft, which is $8\frac{3}{4}$ inches diameter at the lower wheel, 10 inches at the upper wheel, which is fixed at 10 feet 10 inches above the lower wheel, and above this is tubular 38 inches diameter in two lengths joined at the middle bearing by a piece of solid shaft 11 inches diameter; the total length of the vertical shaft being 135 feet. Between the two wheels is the supply chamber, fed from the upper canal by a pipe of 7 feet 6 inches diameter, opening into the side of the chamber, the water flowing upwards and downwards to the guide-blades of two turbines. The pressure upon the bottom of the guide-chamber is carried by the floor which supports this, and no pressure comes upon the lower wheel; but the upper wheel receives on its disk-plate, pressure, from the water, which balances the weight of the

turbines, shafts, &c., so as to entirely relieve the bearings of any downward pressure. Outside each turbine is a closely-fitting cylindrical slide or sluice, which shuts off the discharge of the wheels simultaneously and equally for purposes of regulation, these sluices being automatically controlled from the surface by apparatus in the dynamo-room, so that for a variation of 25 per cent. of load, only 3 per cent. of speed variation will be possible. At a height of about 31 feet above the middle of the guide blade chamber, a 10-ton fly-wheel, 14 feet 6 inches diameter, is fixed upon the wheel-shaft for steadying purposes, and upon the upper end of the shaft is the revolving armature of the dynamo directly attached to the shaft. The fly-wheel is of forged iron; the hollow shaft is built up of steel tube, and the wheels themselves are of bronze, the large supply-pipe being of steel plate. The article is accompanied by illustrations showing the general arrangement of two sets of the described turbines as placed 40 feet apart in a pit, together with detailed drawings to a large scale of the wheels and guide-blades.

W. H. B.

Landslips and Protective Works on Mountain Streams.

By F. Toula.

(Zeitschrift des oesterreichischen Ingenieur- und Architekten-Vereines, 1892, p. 545.)

The Author's investigations of some recent landslips in the mountain regions of Tyrol and Carinthia have been undertaken from the geological point of view, to study the physical causes and characteristics of the occurrences, and the permanence or terminability of these conditions.

The first place visited was Kollmann, on the Brenner pass, where the Gonderbach stream swept down an immense mass of earth into the Eisack valley, causing a severance of the railway communications, and a diversion of the river channel. It is a generic feature of mountain watercourses that at their point of confluence with a larger channel of water, the detritus or alluvial matter (as the case may be) is arrested, and accumulates in shoals or reefs, which may ultimately rise to high crests, or form even considerable hills. The force of the current at the same time impinging on the opposite bank has a twofold—erosive and deflective—action, and thus in repeated forcible variations of course gives rise to many sinuosities. The Gonderbach is usually an insignificant streamlet, the village of Kollmann standing on the crest of detritus. Heavy rainfalls in the narrow portion of the upper valley loosened large masses of earth which, slipping formed a barrier or dam, across the stream, behind which the water collected, until the pressure caused the mass to burst, and swept it and everything in its track down to the Eisack valley. The slopes of the valley show extensive areas of erosion, and the lower ground is accordingly

still considerably threatened; and it is a primary necessity to protect these slopes, and also to clear and maintain an open channel for the stream.

Another landslip which occurred about the same time, in the district of Gailitz, on the Carinthian frontier, was occasioned by heavy rainfall in the mountains above Tarvis, and resulted, not only in the disruption of the lines from Tarvis to Kronan and Pontafel, but also in the destruction of a number of houses, and the devastation of large tracts of cultivated land. The Gailitz river is formed by the union of a number of mountain streams, among which are the Luschari, the Bartolo, the Schlitza, and the Weissenbach. The latter flows down from limestone and dolomitic formations, and on this occasion brought down immense quantities of alluvium eroded by the heavy rains from large denuded surfaces in the upper part of the valley. The first remedial measure was to cut a new channel to prevent the accumulation of water behind the deposited mass; but the source of damage is not touched by such means, and without further measures the evil may at any time be repeated.

A third case examined by the Author was on the Plima, in the Martell valley, where an ice-dam had been formed across the stream some distance below the glacier, and, blocking the valley behind, had finally burst under the accumulated pressure.

In all cases of landslips, great or small, three distinct points are to be noticed, viz., the area of erosion and disruption, the devastated track, and the deposited mass. The whole process can be clearly followed in one *coup d'œil* in the Sécheron, above Bourg d'Aineblanche (Savoy), and at other points of the valley.

In a consideration of remedial measures, it is to be noted that defence, or reparation works in the open valley are perfectly useless without protective works in the higher ground where the damage originates. The maintenance of forests, or the re-afforestation of denuded surfaces is of the utmost importance, especially in limestone districts, where the surface is so readily acted upon and washed away. The surface is protected by a covering of vegetable growth, and the soil is bound by the roots, so that a solid barrier is opposed to the disintegrating action of water. The clearing away of wooded tracts in some high mountain districts has been productive of incalculable evil and loss, for in such situations it is especially essential to consider the after effects of every measure. The constructive means of protection must consist of the clearance and regulation of channels, the erection of weirs and dams, the provision of culverts and bridges proportioned for the maximum flow of flood-water, and the formation of revetment walls; but even these can only be regarded as temporary measures if the exposed slopes are not effectively planted.

In the south of France about 560 square miles have been planted —chiefly with firs—and the limits of protection have thus been extended in many valleys to a distance of 1,650 feet. Up to 1884 the cost of this afforestation was about £1,150,000, while the

estimated expenditure on work to be undertaken during the next sixty years is nearly £9,000,000. In Switzerland about £360,000 have been spent up to the present date, chiefly in glacial tracts.

The Paper is illustrated by several photographs.

P. W. B.

Report of the Administration of the Department of Irrigation (Egypt) for the Year 1891.

By Lieut.-Colonel Justin C. Ross, C.M.G.,
Inspector-General of Irrigation, Egypt.

(4to., Cairo, 1892.)

This Report, like that for the preceding year,[1] contains a full account of the distribution of the waters of the Nile, which during the summer of 1891 were unusually abundant, and during the rather late autumn flood, although less in volume than in 1890, sufficed to irrigate a greater extent of land owing to the completion of additional canals and other new works. The area of cultivated land was 5,704,808 acres and the total expenditure during the year on earthworks, masonry, and Nile protection, &c., was £E.488,928. The year 1891 is remarkable for having yielded the largest cotton and rice crops on record, and a still more notable increase in the quantity of sugar was produced at the extensive Daira Sanieh factories and at the factory of the Sultan Pasha.

The works of repair and of amelioration executed during the year were very numerous; some canals were widened and deepened, others prolonged, and several new canals completed; many regulating bridges were repaired; much land was reclaimed by the drainage of swamps in the Delta provinces and by repeatedly flooding "salaqus" (lands saturated with brackish water) in the Daira Sanieh, to wash out the salt; the railway has been substantially completed from Asyut to Girga, in Upper Egypt, and some additional agricultural roads have been constructed, while surveys and plans have been prepared for many more. Careful studies have been made with a view to the future construction of large reservoirs in which to store Nile flood-water in the distant parts of Upper Egypt, and, including work done in 1889 and 1890, the surveying staff has now triangulated and surveyed in Lower Egypt upwards of 800,000 acres, or, say, 1,250 square miles of irrigated land.

Among works of special magnitude, the Abu Baqarah canal was begun in 1890 and completed in 1891. With a bed-width of 20 metres (65 feet 9 inches), it takes water direct from the Nile, and, passing under the great Ibrahimiyah Canal through an old siphon or aqueduct of seven arches, each 10 feet in width, it is calculated, with a depth of 4 metres (13 feet 2 inches), to

[1] Minutes of Proceedings Inst. C.E., vol. cvii. p. 466.

discharge 7,000,000 cubic metres of water per diem[1] into two basins, together 38,530 acres in extent, which had been cut off from a red water-supply for the last twenty years. The cost of this work was £21,000, and it is estimated that the yield of the land to which it supplies red water will be increased by more than that sum annually. The old siphon existed before the Ibrahimiyah Canal was built, but had been buried in mud and its existence forgotten. It was discovered, repaired, and restored to use by the chief engineer of the circle, Major Brown.

The Qosheshah Escape in Beni-Suef (Upper Egypt) was also begun in 1890 and completed in 1891. It is a gigantic bridge of sixty arches, fitted with horizontally falling gates and the lower tier with direct-lifted shutters working in vertical grooves and raised by winches, and is designed to allow an escape from the river into the adjoining Qosheshah basin of 2,000 million cubic metres of water in twenty days during a high-Nile year, and 1,500 million cubic metres in ten days in a low year. The cost of constructing the bridge and approaches was £62,620.

The restoration of the Rayyah Beherah canal between Cairo and Alexandria, which has been proceeding since 1884 and was taken more seriously in hand in 1888, was completed in 1891, and a special report by Mr. Foster enumerates the extraordinary difficulties of various kinds which were encountered during the progress of the works. The canal runs for some distance on the borders of the desert and was much choked by drifted sand. For its protection and repair sand-screens were erected made of cotton stalks and "tarfa," and by flooding the desert it was found that willow bushes and certain kinds of thick grass with much root could be grown which hold the banks together. Between October, 1888, and May, 1891, the quantity of sand dredged from the bed of the canal was 3,552,729 cubic metres, and altogether the expenditure on the reparation since 1888 has amounted to £177,044; but its completion has rendered it unnecessary to continue pumping water into the irrigating canals at Khatatbah and Atfah, mentioned in the Report for 1890 as an exceedingly expensive process.[2] Moreover, the volume of water provided daily by this canal for the Beherah Province exceeds by 1,500,000 cubic metres that which was supplied by the pumps in 1888 at a cost of £61,255, and this increased supply will produce increased income from land taxes.

A very large number of other important works executed by the Irrigation Department are described in the Report, which is illustrated by a map of Lower Egypt, showing the principal canals, and a diagram showing the effect on the barrage below Cairo of the discharge of water through the large new escape leading into the Qosheshah basin in Upper Egypt.

[1] 1,000,000 cubic metres = 220,462,125 gallons of water.
[2] Minutes of Proceedings Inst. C.E., vol. cvii. p. 469.

O. C. D. R.

Irrigation-Works for the Town of Freiburg im Breisgau.

By — LUBBERGER.

(Gesundheits-Ingenieur, 1892, p. 657 *et seq.*)

The town of Freiburg, which contains about 47,000 inhabitants, without counting the suburbs, has grown so rapidly in recent years that a change in the plan of dealing with the excreta had become a matter of necessity, and after the trial of several dry processes, managed by private contractors, a water-carriage system was introduced, and has since been pretty generally adopted. The disposal of the sewage-water entailed, however, serious difficulties, as the Rhine is 25 kilometres (15·5 miles) distant, and the only streams in the vicinity available for the effluent are too small to take the large volume of foul water untreated.

The experience of sundry other towns similarly situated pointed to the adoption of a tank treatment combined with irrigation. The Author quotes the opinion of Rheinhard, that for each 160 persons an area of 1 hectare would be required, and that of Hobrecht, who considers that the sewage of 250 persons could be treated on the same surface (65 per acre and 101 per acre respectively), and points out that three members of a committee of experts, which included also the foregoing, reported that the sewage of not more than 100 persons should be dealt with on each hectare (40 per acre). In the spring of 1891 a property was obtained at Mundenhof, which comprised 120 hectares of land capable of being prepared for irrigation, 20 hectares of arable land, and 25 hectares of water meadows. Since then further acquisitions have increased the area by 80 hectares, and it was decided to purchase 200 hectares more land to provide for the growth of population. Details are given respecting the choice of the site and the nature of the subsoil. Concerning the volume of the sewage-water to be dealt with, the Author states that a comparison of the figures obtained in the case of certain of the larger towns, Berlin, Danzig, Frankfort, &c., varied from 300 litres to 400 litres per head per diem (66 gallons to 88 gallons), and it was resolved to assume a daily maximum flow of 350 litres (77 gallons), and a possibility of having to dispose of the sewage of double the present population. This per second is equivalent in round numbers to

$$\frac{94{,}000 \times 350}{24 \times 3{,}600} = 380 \text{ litres } (83{\cdot}6 \text{ gallons}).$$

A detailed plan is appended of the laying-out of the works, and the two depositing tanks, each 30 metres by 14·4 metres, are shown in plan and section. Full particulars with illustrations are given of the arrangement of the carriers and under-drains. A feature of these works is that, owing to the rapidity of fall, it became possible in certain places to store up the subsoil drainage-

water and so to pass it a second time over and through the land. By this system a more complete purification is said to be obtained, and the manurial value of the sewage is thus more fully extracted. Moreover, an increased supply of water is provided for irrigation purposes, which is of importance during the dry summer months.

The total outlay, which includes the purchase and adaptation of the land, was in round figures 1,000,000 marks (£50,000). Much of the area acquired was covered with forest trees, and full particulars are given of the expense of removing them and of extracting the roots, &c. Detailed analyses are furnished in a tabulated form of the composition of the sewage-water at each hour of the day and night, together with comparative analyses of the effluent water from the under-drains. The sewage and the effluent were also submitted to a bacteriological examination by Professor Schottelius, and the results, which are stated to be very satisfactory, are appended.

G. R. R.

The Question of the Water-Supply for the Extended Municipality of Vienna.

(Gesundheits-Ingenieur, 15 September, 1892, p. 559.)

At the end of 1891 the whole of the outlying suburbs were incorporated with the central municipality of Vienna proper, by which means the population was at once raised from 817,000 to 1,342,000.

These suburbs at the present time possess no water-supply worthy of the name; and the inhabitants desire, among the privileges appertaining to a great community, beyond all others the advantage of a regular service of water. The choice of a source from whence the supply is to be derived has occasioned great differences of opinion among the authorities and those interested. The present high-pressure supply is derived from the Kaiserbrunnen and the Stixensteinerquelle, which are springs in the Schneeberg district. When the flow of these natural springs is inadequate, recourse is had to the pumping-station at Pottschach. The daily minimum outflow from the above springs is about 17,200 cubic metres (3,784,000 gallons). The volume that may be derived from the pumping-station is 8,000 cubic metres. The insufficiency of this supply has induced the authorities to increase it, and the contemplated works are to be completed at about the end of the present year,[1] by which a further volume of 35,800 cubic metres will be obtained from additional springs in the Höllenthal and elsewhere, making a total supply about equal to

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[1] Minutes of Proceedings Inst. C.E., vol. c. p. 451.

61,000 cubic metres (13,420,000 gallons). The aqueduct will be constructed to convey a daily flow of 138,000 cubic metres.

The population may then be assumed to reach about 1,700,000 in 1900, and in the year 1910 will probably amount to about 2,000,000. As the average domestic consumption is now about 25 litres per head per diem, the above volume will be ample for all purposes, including road-watering and industrial uses; but the increased supply of 61,000 cubic metres will afford sufficient water for the wants of the population in 1910, as respects domestic consumption only.

When, however, the requirements for road-watering, for gardens, for baths, and other various industries are taken into account, the volume above indicated will manifestly be quite insufficient, as a total of not less than 100 litres (22 gallons) per head per diem will be needed. It is pointed out that for these latter purposes an ample supply may be drawn from the Danube, without materially affecting the flow of the river.

In a recent discussion on this question, the difficulties of obtaining a greatly augmented supply from springs was insisted upon; and it was stated that the original intention of constructing a gallery or adit 7·5 kilometres in length for the purpose of collecting the underground water had been abandoned in favour of a group of tube-wells connected by a net-work of pipes. The water obtained by this means to be conveyed to a sump, and lifted by pumps into a high-level reservoir, connected by an aqueduct with the present reservoir on the Rosenhügel. It is urged against the former scheme that the great underground stream to be drawn upon might perhaps be speedily exhausted, as had been the case at Konstanz, and that the very long adit might be injured by an earthquake. It was also stated that it would be imperatively necessary to seek at once for a duplicate service of second-rate water, as no important city is at present dependent on a single water-service of unexceptional quality.

G. R. R.

Water-Power Dam on the Colorado River at Austin, Texas, U.S.

Reports by the Austin Board of Public Works and by E. W. Groves, Engineer in charge of construction.

(Engineering News, New York, January 26th, 1893.)

The object of this dam is to supply the City of Austin, which is at a distance of 3 miles from it, with water, and also with electric light and power. It consists of a strongly-built wall 1,275 feet in length, 66 feet wide at the base, and 60 feet in height above low-water level, the total cubical contents being 95,000 cubic yards. Both faces, up-stream and down-stream, are constructed of blocks of granite, and the interior of blocks of lime-

stone of good quality, the maximum size of the granite being 93½ cubic feet, and of the limestone 5 cubic yards. All the mortar used in the work is required to be of 1 part Portland cement and 3 of sand. The up-stream face is perpendicular, while, in order that flood-waters may pass down it in a gliding sheet and deliver the water to the lower level without a direct blow, the down-stream face is built at the crest on a convex curve of 20 feet radius, and then with a batter of 3 in 8, until, at 25 feet from the ground, it curves outwards with a radius of 31 feet down to the toe of the dam.

Close below the east end of the dam a power-house will contain 4 pairs of horizontal turbines each of 506 HP., under 54 feet head of water, having on each turbine-shaft two pulleys from which belts will be led to dynamos, three of them to be used for supplying light and one for supplying power. There will also be two vertical turbines, each of 200 HP., under 54 feet head, each shaft of which is to be connected with a pump by means of a bevel gear; and two pairs of horizontal double-acting pumps of the plunger type, each pair of a capacity to deliver 4,000,000 gallons per twenty-four hours. The water from the lake will be conveyed to the turbines through eight penstocks, or iron tubes, 9 feet in diameter.

On the west side of the river, 1¼ mile from the dam and 4 miles from the city, a settling-basin, or reservoir, with a storage capacity of about 100,000,000 gallons, is to be built at a height of 300 feet above the low-water level of the river, and 115 feet above the highest point of the city; and there are two other places close to it where reservoirs, each of 50,000,000 gallons, can be added whenever the city requires them. The supply-main, 24 inches in diameter, will be carried across the river from the pumps to the west bank on corbels projecting from the face of the dam, and the distribution of the water in the city is provided for by 42 miles of cast-iron pipes, ranging in size from 6 to 24 inches in diameter, with one hundred and sixty-nine valves and two hundred and thirty double-nozzle fire-hydrants.

The most notable piece of machinery employed in the construction of the dam is an overhead ropeway along which all the materials for the work have been conveyed. The west bluff rises nearly vertical to a height of 65 feet above the crest of the dam, while the east bluff rises only 10 feet above the dam, and the cable is suspended on two towers, that on the east side, in which the hoisting engine is situated, being 70 feet high, and that on the west bluff 30 feet high. The main cable on which the carriage moves is 2½ inches in diameter, 1,850 feet long, and 1,350 feet between the points of support, which is the greatest span of any hoisting cable in existence.

The limestone quarry is on the west side of the river and 1,200 feet up-stream from the dam, and the blocks of limestone are brought to the side of the dam and there unloaded with a steam derrick, being then transported by the cable to any portion of the

work. The granite is brought by railway from quarries at 60 miles distance to the easterly end of the cable and then dealt with in the same way. The sand and cement for the mortar are similarly conveyed by the cable in loads of about 5 tons to be mixed on the wall near the workmen.

The work of excavation was commenced in October, 1890; the construction has often been interrupted by floods which have raised the level of the water as much as 43½ feet, but it is believed that it will be completed in the course of this summer. In order to obviate difficulties which might arise hereafter from the stoppage of the entire flow of the river, three cast-iron pipes of 3 feet diameter have been laid through the dam near the west side at 13½ feet above low-water, with valves set in the dam 12 feet from the up-stream face. Access is given to these valves by a chamber 4 feet × 6 feet × 15 feet, with a manhole to the top of the dam.

Also, as these pipes might not pass sufficient water, passages have been left through the dam at varying elevations, which are closed with heavy timber gates supported on a sill of granite which projects about 2 feet from the face of the wall, and resting against upright posts fitted to the face of the dam.

The minimum flow of water is about 1,000 cubic feet per second; the maximum, 250,000 cubic feet. The area of the lake formed by the dam is 2,000 acres. The approximate cost of the entire plant, including dam, power-house, reservoir and distribution system, will be £280,000.

O. C. D. R.

Report to the Director-General of Public Works of the Argentine Republic on the Present State of the San Roque Water-Dam.

By Federico Stavelius. (Two Illustrations.)

(Anales de la Sociedad Cientifica Argentina, Buenos Ayres, September, 1892.)

The San Roque dam, constructed for the purpose of supplying water for the irrigation of the lands around the city of Cordoba (terminus of the Central Argentine Railway), is 115 feet in height, with a width of 16 feet 5 inches at the parapet, and forms a reservoir capable of holding 260 million cubic metres of water, which is a very much larger volume than is contained in any other reservoir in the world. Completed in 1889, the water during 1890 and 1891 stood generally at a height of from 100 to 110 feet, but the leakage was so great that in January, 1892, the reservoir had to be emptied. A very careful examination of the work having been instituted by the Author, he reports to the Government that its construction is in many ways defective. It is built of rubble masonry—not even coursed—with inferior mortar only partially hydraulic, carelessly executed as piece-work, the stones apparently thrown in anyhow, and very insufficiently

mixed with the mortar. Only the external face is rather less unsatisfactory. The upper 40 feet of wall have leaked so abundantly that much of the mortar has been washed out of the masonry, and what remains is impoverished from the lime having been dissolved. The back of the dam is now covered with a hard coating of carbonate of lime, resembling stalactite, from $\frac{1}{3}$ to $\frac{1}{2}$ inch thick. Much sand has also been washed out.

There are also many cracks in the masonry, one of which, in the centre of the dam, appears to extend right through from face to face of the wall; and these the Author attributes to the excessive vibration which occurred during twelve days in February, 1891, when large volumes of overflow water poured through the side-escapes at the top of the dam. He explains that by an error of construction these escapes have not been continued far enough, but stop at a point where the heavy body of surplus water falls from the height of 40 feet into the river bed below the reservoir. Even the tiles on the roofs of buildings at some distance were violently shaken by the thunder of these cascades.

Nevertheless the leakage does not seem to occur until the water reaches a height of 72 feet (22 metres), and the Author strongly advises that, so far as possible, the reservoir should never be allowed to be filled above that height. Even then it would contain 56,000,000 cubic metres of water, which is more than double the contents of any of the largest reservoirs in Europe or in Algeria, and would suffice to thoroughly irrigate 33,000 acres of land, which he believes is as much as is necessary at present. It is suggested that a storage capacity of 260,000,000 cubic metres is excessive, and a list is given of the twenty-six largest reservoirs in the world, which shows that, omitting two in the United States, the combined storage power of the other twenty-four amounts to only 225,000,000 cubic metres.

It might, however, be difficult to limit the rise of the water to a height of 22 metres (72 feet), owing to the great rapidity with which the reservoir is sometimes filled. Thus, on the 20th of December, 1890, in the course of six hours the volume of water was augmented by 42,550,000 cubic metres, whereas, with the existing means of discharge, it would require four days and a half to reduce it by that amount. It is therefore a matter for serious consideration whether additional overflow escapes should not be provided at the height of 22 metres, by tunnelling through the rock upon which the dam rests at either extremity.

Owing to its proximity to the city of Cordoba a collapse of this dam would be very disastrous, and might occasion the loss of thousands of lives; and it must be borne in mind that the dam at Habra, in Algeria, which was constructed in 1866–71, to hold 30,000,000 cubic metres of water and collapsed in 1881, very closely resembled the San Roque dam in height, in shape, in the inferiority of the mortar and other materials with which it was built, and in many other respects. That calamity was also preceded by great leakage and the deposit of a hard coating of car-

bonate of lime covering the surface of the wall. When the Habra dam collapsed, a length of 328 feet of wall by 108 feet in height was borne down by the flood, causing the destruction of several villages, besides part of the town of Perregaux, and the loss of two hundred and nine lives.

Together with other minor ameliorations, the Report recommends that, in order to render the reservoir safe, the dam should be strengthened and rendered impermeable by the construction of a brick wall, 2 feet 6 inches or 3 feet thick, covering its whole face from bottom to top. In plan this wall should be convex, curving outwards against the pressure of the water, the bricks to be laid with mortar formed of 1 of Portland cement to 2 of sand, and the space between it and the existing dam should be filled up with hydraulic concrete well rammed down. This wall must be built with the greatest attention to every detail, of the very best materials, and externally coated with hydraulic cement; its main object would be to stop the leakage, but it would also add to the resisting power of the dam. The existing overflow channels should also be continued until they reach the river bed, so as to put a stop to the vibration caused by the before-mentioned cascades. By these means there would be little danger of the reservoir collapsing, even if unavoidably filled for a few days to the brim.

Plans and sections of the dam, showing the position of the leaks, &c., accompany the Report.

O. C. D. R.

The Demolition by Blasting of the Water-Tower at Charlottenburg-Westend. By Major Gerding.

(Glaser's Annalen für Gewerbe und Bauwesen, January 15th, 1893, p. 22.)

At the meeting of the Verein für Eisenbahnkunde in December last, the Author gave an account of the demolition, under his directions, of the colossal structure known as the Germania Tower, in October 1892. The original cost of the building was, it is stated, 6,000,000 of marks (£300,000). It occupied a commanding position in the western suburbs of Berlin, and was a prominent feature in the landscape. It consisted in the main of an iron circular tank destined to contain 440,000 gallons of water; this tank rested on arches, supported by thirty-six columns. The bottom of the tank was at a height of 98 feet above the level of the ground, and the diameter of the basement of the substructure was about 197 feet. Above the tank was a lofty dome rising to a total elevation likewise of 197 feet. For reasons with which the Author was not acquainted, but probably because the supports were not considered strong enough to bear the enormous load, the building was never used for the purpose for which it was erected. For many years it had remained an unoccupied and useless ruin,

and as the land was wanted for other buildings, its demolition was urgently needed. It had been sold for old materials for £1,750, but it would not repay the cost of pulling it down, and it was therefore decided to destroy it by blasting. The police authorities had, however, intervened and had forbidden this proceeding, in the interests of adjoining householders, and affairs remained for a long time at a dead-lock. Ultimately on the Author's report that the work could be done without any injury to the neighbourhood, the prohibition was withdrawn and the blasting operations herein described were carried out. The various phases in the demolition are illustrated by photo-process blocks. Permission was only granted in the first instance to throw down three columns at a time, and as the Author had arranged to destroy the whole building at one operation, he declined to undertake the blasting under these circumstances, because he did not wish to be hampered by any conditions in the execution of his projects. These entailed the simultaneous lifting of the entire structure in a horizontal plane by discharges fired by electricity under each of the thirty-six columns. In this way he conceived that the building would crumble together and fall, almost within its own area, and with the least possible damage to surrounding dwellings. He was, however, induced to accept the police regulations, and three columns were at first blown down successfully on the morning of the 14th October by the discharge under each of 13·2 lb. of gelatine-dynamite, in well tamped chambers. The Author states if the charges are scientifically disposed and well tamped, that for each square yard of horizontal section of large masses of masonry to be destroyed, from 1·8 lb. to 2·2 lb. of dynamite, gun-cotton, and similar explosives are required. The result of the first blasting was as anticipated; the three columns fell without any detonation worth speaking of, and a wedge-shaped slice of the structure was removed, as shown in a photograph. At a second blast with 264 lbs. of dynamite, twenty columns with the bulk of the building were successfully destroyed at four o'clock the same afternoon, only a portion of the side of the building remaining as a screen to other houses. This portion was demolished next day, with the exception of three columns, which were subsequently removed separately, and the whole building, estimated to weigh 393,680 tons, was thrown down with about 440 lbs. of dynamite, or about 1 lb. of dynamite for each 900 tons of masonry—a striking illustration of the explosive force of this material.

G. R. R.

The Dyke-Constructions of the Minyans. By E. Curtius.

(Sitzungsberichte der Akademie der Wissenschaften zu Berlin, 1892, p. 1181.)

The traces of an ancient civilization in the interior of Bœotia, first brought to light by Lord Elgin, and subsequently confirmed and illustrated by the researches of Schliemann, have in recent times been amplified and extended by discoveries which throw all previous investigations into the shade, namely, those which have to do with the drainage of Lake Kopais, and which give evidence of a great and comprehensive scheme of ancient engineering, due to the enterprise of the Minyans. The Author describes the pestilential swamp which ensued upon the destruction of these works, and the fruitless efforts of the Turkish rulers to restore them, until at last the undertaking was handed over to a company of French engineers, whose activity has made known the value and importance of these marvellous reclamation and drainage works of pre-historic times. By means of a map of the lake and of the surrounding country, the nature of the works of the Minyans, which were of a threefold character, is made clear. First the Rivers Kephisos and Melas had to be regulated and carried through the deepest portions of the valley to the north of the basin. This was accomplished by the so-called "canal of the left bank." For this purpose fan-shaped embankments had to be formed to keep back the rivers into a canalised bed. The steep rocky shore on the northern side of the lake formed one bank of the canal, the other being marked out by substantial dykes. A second channel (the central canal) was carried across the middle of the lake; the entrance of this canal was likewise fan-shaped to receive as in a funnel the waters of Mount Helicon and of the numerous springs which issue on the south-western shores of the lake. This channel, which needed for its construction not less than 100 cubic metres of earth for each lineal metre, has now in part disappeared. A third channel, the "canal of the right bank," can be plainly traced along the south shore of the lake, and circling round the eastern extremity, it joined the central canal and passed with it as far as the Bay of Topolias, where all three canals become united and discharged into the great Katabothren. In this last portion of the canal, where all the branches are joined in one, the work was of extreme solidity, the massive dykes being lined on the interior, where exposed to the force of the stream, with masonry of the polygonal type found in the most ancient portions of Tiryns and Mycenæ. No sufficient information is yet at hand to speak positively concerning the Katabothren and the mysterious underground connection between Lake Kopais and the sea. But an artificial tunnel 2 kilometres in length in the neighbourhood of Larymna is incomplete and probably belongs to the efforts made to drain the lake in the time of Alexander the Great. This tunnel, which has the sixteen shafts formed for its construc-

tion, resembles in all respects the Roman works on Lake Fucinus. Numerous traces remain of other attempts to draw off the water of Lake Kopais, generally by means of open canals. In ancient times the waters passed into caverns in the rocks (Katabothren) some twenty of which are known on the eastern side of the lake, and the entrances to these caverns were then carefully cleared, widened and kept free from detritus by regulated water-courses and dams. By means of underground channels the water in all probability escaped from these caverns into the sea. In course of time, however, they became choked up, the channels were destroyed and the whole country was converted into a swamp. The Author calls attention to the magnitude and importance of these ancient works, and investigates the probable origin of the people to whom they were due. The Minyan race, who were undoubtedly Argonauts, and who are said by Herodotus to have introduced the art of writing into Greece, were skilful dam-builders, and must have been a powerful people to have planned these works, and to have founded prosperous cities round the shores of Lake Kopais, which 3,000 to 4,000 years ago they converted into a fertile and highly cultivated tract.

G. R. R.

The Disinfection of Town Sewage-Water by Means of Lime.

By Professor Pfuhl.

(Zeitschrift für Hygiene, 1892, p. 509.)

Many towns, in default of irrigation-farms, are compelled to purify their sewage by chemical means before its discharge into rivers; and it would seem from the Transactions of the German Public Health Society that, as a rule, more attention has hitherto been paid to clarification than to disinfection. The Author remarks that in certain cases, as for instance, where typhoid fever or cholera may be present, it is most important that the sewage-water should be disinfected, as it might otherwise communicate the germs of those diseases to persons using the river water mingled with the effluent for drinking or for domestic purposes. Among the chemical substances most largely used in sewage treatment is lime, itself an excellent disinfectant; but it seemed doubtful whether this material, in the way in which it is now employed, really serves to destroy the bacilli of typhoid fever and cholera. In order to determine the question, the Author investigated the proportions in which lime must be added so as to effect this object. Attention is directed to his previous experiments with lime,[1] in which he found that the addition of 1 per cent. of milk of lime (which was equivalent to 1·37 per mille of slaked lime) was

[1] Minutes of Proceedings Inst. C.E., vol. xcvii. p. 459.

sufficient to disinfect the Berlin sewage-water, containing the bacilli of typhoid fever. It was, however, necessary to complete the investigation of this subject, and to carry out the experiments more fully. Previous tests had shown bouillon to be more favourable to the development of the germs than either gelatine or agar-agar, and the cultivations therefore took place at blood-heat in bouillon. The Berlin sewage-water, when in a fresh condition, is dark gray in colour, and has a sickly disagreeable smell. It was, in all cases, slightly alkaline, and needed 1 per mille of normal acid to render it neutral. After sterilization of the sewage-water, at a temperature of 160° Centigrade, and at a pressure of 5 atmospheres, the alkalinity was slightly increased. In each case 50 cubic centimetres of sewage-water received $\frac{1}{4}$ of a cubic centimetre of a 24 hours' old bouillon-culture of typhoid fever, or cholera-bacilli. The liquid thus contained about the same number of germs as did the fresh sewage-water. It was necessary first to sterilize the sewage-water, in order to study the behaviour of these special bacilli without the interference of the numerous other species usually present. For reasons given, the lime was used in the form of a dry powder, obtained by calcining marble, and slaking 100 grams of the same with 60 per cent. of distilled water. After the introduction of the lime, the flask, with its contents was kept in constant movement, to prevent the settling of the suspended matters and the precipitate. Several flasks of each test were filled simultaneously to give parallel results. The lime was used in the proportion of $\frac{1}{4}$, $\frac{1}{2}$, and 1 per mille. To determine the rapidity with which the lime did its work, the Author withdrew samples for culture at stated intervals. From the first set of tests, which are recorded in the form of a Table, it is seen that only the 1-per-mille dose of lime was fatal to the germs under all conditions; though the $\frac{1}{2}$-per-mille solution destroyed all germs after two hours' exposure, and subsequent experiments proved that even 1$\frac{1}{2}$ hour's action of the lime was sufficient. In a second table are shown the results of adding lime to sterilized sewage-water, into which a proportion of typhoid and cholera germs had been introduced on agar-agar, and therefore in the absence of nutritive bouillon. In this case also the lime proved as efficacious as before.

In a further series of experiments the Author investigated the influence of lime upon sewage-water not previously sterilized. For this purpose twelve samples of fresh sewage were collected in flasks, and the contents of six of these flasks were sterilized, the others remaining untreated. To four of the sterilized flasks $\frac{1}{2}$ per mille of lime was added, and to the other two 1 per mille. The six flasks of untreated sewage had in each case $\frac{1}{2}$ per mille more lime than the former ones, namely, four of them 1 per mille, and two of them 1$\frac{1}{2}$ per mille of the lime. The contents of all the twelve flasks having received a fragment of agar-culture of typhoid bacilli, were examined at intervals of 1 hour and 1$\frac{1}{2}$ hour, and from these tests also it appeared that a dose of 1 per mille of lime was

needed to destroy all germs of cholera and typhoid fever in from 1 to 1½ hour; it being a condition, moreover, that the liquid should remain throughout this time in motion. For sewage at rest, the Author's experiments led him to the conclusion that not less than 3 per mille of lime would be needed. At no existing sewage-works is the lime employed at present in sufficient quantities to destroy the pathogenic germs, and its value as a disinfectant is often partially neutralized by the use with it of sulphate of alumina. The Author points out that a valuable index of the sufficiency or otherwise of the lime treatment is afforded by the alkalinity as tested by titration of the effluent with normal acid, and he has calculated a scale for this purpose.

G. R. R.

The Subsoil Water of Kiel, with Special Reference to the Iron Contained therein, and to Experiments Undertaken to Effect its Removal. By Professor Bernhard Fischer.

(Zeitschrift für Hygiene, 1892, p. 251.)

The Author points out that the prevalence of the recent cholera epidemic has emphasized the importance of obtaining a water-supply which shall be in all cases absolutely free from disease germs. He shows the nature of the attempts made in the past to attain these results, and he maintains that the failure, in certain named instances, of careful sand-filtration to remove cholera-bacilli, has proved that artificial filtration cannot compete with the process as carried out by Nature herself in the case of water passing through the soil. The difficulty of obtaining an adequate supply of water from the subsoil has been successfully overcome in recent times in the works for several of the larger cities, and now that the possibility of freeing such water from iron has been demonstrated, the objections hitherto urged against supplies of this character cease to have any weight. A short account of the water-service of Kiel, which furnishes a case in point, may be of use at the present time, partly because it presents also a series of careful experiments extending over a considerable period, and partly because it illustrates the behaviour of the iron in the water and its successful elimination by artificial treatment.

Kiel, situated at the southern extremity of a land-locked bay, and having a population of about 70,000 persons, is supplied with subsoil water conveyed in two separate services. The one having works situated at Gaarden has been in operation since 1880, and derives its water from 17 shallow wells, steined round and sunk to a depth of from 19·6 to 26·2 feet. These wells vary in diameter from 5 feet to 6 feet 6 inches, and they are situated in a district not under cultivation and to which the public have no access. They are all covered over at the top, and the steining,

which is carried up some 3 feet above the level of the ground, is rendered, as respects the upper portion, as far as possible impervious to percolation. The water is conveyed into a collecting reservoir and is from thence lifted by pumps. The yield of the works, which was originally 880,000 gallons of water per diem, has now sunk to about half this volume. The second supply is taken from the neighbourhood of the Schulensee, a fresh-water lake, some 3 miles distant from the town. These latter works, which have been in operation since 1889, were planned to distribute filtered water from the lake, but they now provide subsoil water only. It was found that in a water-bearing stratum of gravel passing beneath the lake, there was abundance of water which had no connection with that contained in the lake, as it rose to a height of 65 feet above the level of the lake in iron pipes sunk into the ground for experimental purposes. A shaft was therefore sunk into the gravel in the centre of the lake, about 164 feet away from the shore. This shaft is in its lower portion 13 feet in diameter; at the upper part it is, however, 6 feet 6 inches only in diameter. It is constructed of wrought-iron rings, most carefully put together to exclude the lake water; the upper rings are double, the space between them being filled in with concrete. It is sunk to a total depth of 65 feet and penetrates the gravel for a thickness of about 26 feet. Two other wells have subsequently been sunk on the shore of the lake to a depth of about 30 feet. The water from these wells is lifted into a storage tank, and from thence raised by pumps into the high-level reservoirs which supply the town. These works yield about 1,100,000 gallons per diem, the total water-supply being thus about 1,540,000 gallons daily, and the average consumption varies from 16·2 to 18·2 gallons per head per diem. Particulars are furnished of additional works now in hand to further increase the volume of water, and Professor Haas has recently reported on the probability of the discovery of large underground supplies in the vicinity of Kiel.

The Author records the results of very numerous tests of the different samples of water taken in this district, among others of 661 wells, all but 309 of which were open to suspicion in consequence of their impurity; also of the analyses of subsoil water and of samples of the town water taken every month, since September 1889, under an arrangement with the municipal authorities. An apparatus is described by reference to a diagram which was employed for taking specimens of water at any required depth for bacteriological examination. Full details are given of the methods resorted to for the chemical and other tests.

The subsoil water over a large district surrounding the town was found to be remarkably uniform in its composition, and it was somewhat peculiar from the fact that it invariably contained small quantities of iron, and that notwithstanding the presence of a comparatively high percentage of organic matter and a small proportion of ammonia, both nitrous acid and nitric acid were

entirely absent. The following results were obtained from a careful analysis of the water in question :—

Silica	25·5	Chlorine	18·0
Protoxide of iron	3·7	Phosphoric acid	5·0
Alumina	0·8	Ammonia	1·6
Lime	137·6	Potash	4·7
Magnesia	18·2	Soda	22·0
Sulphuric acid	6·7		

Total carbonic acid	303·7
Ditto, as mono-carbonates	133·0
Free carbonic acid	39·0

All the above values are expressed in milligrams per litre. The specific gravity was 1·0003. The results of the bacteriological examination are also set forth. In the case of certain of the town wells the following values were obtained :—

		Germs per Cubic Centimetre.
51 wells contained an average of	less than	500
34 „ „	between	500 and 1,000
64 „ „	„	1,000 „ 10,000
22 „ „	„	10,000 „ 20,000
8 „	more than 30,000 germs capable of development.	

In no case were disease-germs recognized, and the artesian wells were as a rule comparatively pure. Certain of the latter contained respectively, 1, 14, 7, 82, 90, 33, 10 and 94 germs per cubic centimetre.

Owing to the iron it contains, the water of Kiel, on its extraction from the soil, undergoes changes which impair its value for domestic consumption. Freshly drawn water is as a rule clear and colourless, but after standing for a time in open vessels it at first turns milky and later becomes filled with a bright brown deposit, which slowly sinks to the bottom, leaving the supernatant liquid clear, in which condition it remains without further change. The precipitate consists of the hydrated oxide of iron. In the case of the Schulensee water, the deposits are found under the microscope to consist of threads of crenothrix and cladothrix encrusted with the iron-compound. The separation of the iron proceeds with considerable rapidity; thus in twenty-four hours the amount of iron present fell from 2·22 milligrams per litre to 0·081. The contents in carbonic acid decrease in the same way. The reasons for these reactions are fully considered and discussed.

When the Schulensee works were first started in 1889, complaints respecting the quality of the water speedily arose, and measures had to be undertaken to remove the iron. The Author was indebted to Dr. Koch for an account by Dr. Proskauer of Mr. Oesten's process for dealing with a similar difficulty in the case of the water-supply of Berlin,[1] and he details the experiments undertaken at Kiel to test this process. The principle relied upon is the thorough aeration of the water which is caused

[1] Minutes of Proceedings Inst. C.E., vol. ciii. p. 439.

to fall through the air for some distance in a finely divided state as rain or spray, and its subsequent rapid filtration through gravel or coarse sand. Mr. Piefke substitutes a coke tower for the rain drops, as exposing a larger surface of the water to the action of the air, and facilitating at the same time the expulsion of the carbonic acid gas, owing to the formation of aqueous vapour. An account is given of a protracted series of experiments to test the efficacy of both these systems of treatment for the Kiel water, to ascertain the minimum height needed for the rain-drops, the best rate of filtration, the proper form of filter, and the thickness of the filtering materials, the relative values of sand and gravel, &c., and the results are set forth in a series of tables.

The Author insists upon the value of a period of subsidence in a shallow tank between the aeration and the filtration, because by this means a considerable proportion of the iron becomes precipitated and sinks to the bottom of the tank, and therefore is prevented from clogging and choking the pores of the filter. Water which before treatment contained 5·23 milligrams per litre of protoxide of iron had but 0·12 milligram after treatment by Mr. Oesten's process, and only a trace of iron remained in the filtered water after treatment on Mr. Piefke's system. Some equivalent results were obtained by the use of the artificial stone filter of Messrs. Fischer and Peters of Worms. These filters are formed of hollow blocks of sandstone, composed of coarse grained sand cemented together with silicate of soda and lime. The water to be filtered in this case soaks into the cavity of the block, and thence finds its way into the effluent water-pipes.

G. R. R.

Evaporation by Multiple Effect. By Teile H. Müller.

(Proceedings of the Engineers' Club of Philadelphia, 1892, p. 257, 5 plates. Philadelphia, 1892.)

The Author remarks that, from a purely engineering standpoint, one cannot help being surprised by the close analogy between the evolution of the evaporating-apparatus and that of the steam-engine. As in the steam-engine, there appeared first the old atmospheric engine, then the Watt condensing-, and, lastly, the modern high-class condensing-engine using the steam expansively, so in evaporation, first came the old open kettle, then the vacuum-pan, and lastly, the multiple-effect evaporating-apparatus, which also uses steam expansively and employs condensation. Indeed it may be questioned whether the practice of using steam expansively in a steam-engine, or the application of this same expansion of steam in evaporators, is of the greater importance to the preservation of the stock of fuel.

As instances of the many industrial processes dependent upon evaporation and using large quantities of fuel, the manufacture of

sugar, of salt, of ice from distilled water, of soda, glue, meat-extracts, milk and colours are mentioned. The total weight of sugar produced in the season 1888–89 was in round numbers 2,665,000 tons of beet-sugar and 2,371,000 tons of cane-sugar. The first evaporation of the juice and also the subsequent refining, which operations have been hitherto and are still very frequently effected in ordinary vacuum-pans, occasion a large consumption of fuel, but by the use of improved multiple-effect evaporators in beet-factories the fuel does not much exceed 1·1 lb. of coal per lb. of sugar; and the entire evaporation of cane-sugar is performed with the refuse of the cane as fuel. The apparatus there referred to was originated and first patented by Mr. Rillieux, of New Orleans, many years ago; it was first made in Europe by Robert, in Seelowitz (Austria), and spread rapidly over the sugar districts in Europe. It has also been adopted in the West Indies.

A considerable proportion of the salt made in the United States is still produced in open pans. These consume about 1 lb. of coal for 2·4 lbs. of salt produced, which is equivalent to about 7·9 lbs. of water evaporated per lb. of coal, while a triple-effect evaporator at the same establishment required only 1 lb. of coal for 5·4 lbs. of salt.

Again, ice-manufacturers and others requiring pure distilled water evaporate from 8 to 10 lbs. of water per lb. of coal, but by using multiple-effect evaporators 40 lbs. of sea-water are evaporated by 1 lb. of coal, and it is believed to be possible to evaporate 50 lbs.

These results are due to the utilization both of the latent heat of steam and of the heat contained in the evaporated vapours during the process of evaporation; and the multiple-effect apparatus consists of a number of vessels, practically two, three, or four, sometimes five or six, connected with each other in such a manner that the vapour generated in the first vessel is taken to the heating surface or chamber of the second, the vapours of the second vessel to the heating chamber of the third, and so on. The vapour generated in the last vessel is liquefied in the condenser, which is a very important part of the apparatus, and should be cooled by the injection of a spray of water, with as high a vacuum as possible. The first of the vessels receives the heating steam from the boiler direct, or sometimes it may be supplied from a receiver in which the exhaust-steam from all the different engines, pumps, &c., in the factory is collected.

Multiple-effect evaporation involves a larger amount of heating surface than is necessary when single pans are used, which implies also increased first cost of the apparatus, and for this reason single-effect evaporation is still employed where even a double-effect would very soon pay for the difference in the first outlay.

The apparatus used in sugar-factories is described in much detail, and illustrated by a variety of drawings.

O. C. D. R.

The New High-Duty Pumping-Engine of the Boston Waterworks.

(Engineering News, New York, vol. xxviii., 1892, p. 578.)

The engine is of the inverted vertical triple-expansion type with cylinders 13·7, 24·375, and 39 inches diameter, under stroke of 72 inches, actuating three cranks at angles of 120°, of which the low-pressure leads, through the medium of links connecting the crossheads with modified bell cranks, from which, connecting-rods actuate the crank-shaft at one side of the engine, and the pump plungers on the other side; these being inclined about 30° from the horizontal, and having a stroke of 48 inches only, as also have the cranks, being thus reduced below the piston stroke by the agency of the bell cranks. The steam and exhaust valves are gridirons worked by cams driven by gearing from the crank shaft, the high-pressure cut-off cam only being regulated by the governor. The steam to the first cylinder passes through a separator, then exhausts through a tubular re-heater to the intermediate cylinder, and again through a second reheater to the final cylinder, the heater tubes having boiler steam (185 lbs.) inside them, and all the cylinders are jacketed on ends and barrels, the jackets of the low-pressure, however, with steam reduced to 100 lbs. only, and draining to the feed-heater, all other reheaters and jackets draining back directly to the boilers. The pump plungers are double-ended, ogival headed, and work against a pressure of 55 lbs. per square inch, a portion of the discharge of one pump going to the force main *viâ* the surface condenser. All the pump valves have the Riedler positive closing gear to prevent reflux and shock. The plungers travel at a speed of 400 feet per minute, the steam-pistons moving at 600 feet, the revolutions per minute being 50. The clearance volumes in the cylinders are 3·1 per cent., 3·8 per cent., and 5·2 per cent. respectively. The crank shaft carries a fly-wheel of about 15 feet diameter, and the output in 24 hours is 20,000,000 gallons.

The article is illustrated.

W. H. B.

A Large Compound Pumping-Engine.

(Oesterreichische Zeitschrift für Berg- und Hüttenwesen, 1892, p. 427.)

A large horizontal receiver compound condensing pumping-engine was in April 1891 completed by the Buckau Engine Works, of Magdeburg-Buckau, for removing the water from a colliery shaft in Russian Poland, which was drowned out in 1890. It is intended to lift 20 tons of water per minute from a depth of 541 feet when working 10 revolutions per minute, or to develop about 1,500 HP. at 12 revolutions with 75 lbs. initial pressure.

The pitman, supplied by Messrs. Haniel and Lueg, of Dusseldorf, is attached to two bell-cranks over the top of the shaft, driven direct by the engine. The cylinders are arranged tandem fashion, and are raised upon a masonry pediment to such a height above the shaft collar that the piston-rods and connecting rod are in line when the bell-cranks are in mid position, the latter being coupled to the back crosshead of the low-pressure cylinder, while the flywheel is attached to the forward end. The piston diameters are 63 inches for the high-pressure and 98½ inches for the low-pressure cylinder; the length of stroke is 98½ inches. The capacities of the two cylinders being in the proportion of 1 to 2·44, the work done by the steam entering at 75 lbs. and exhausting at 9 lbs. absolute pressure, is exactly equal in both. The low-pressure piston-rods are hollow cylinders of cast steel of 15¾ inches external diameter and about 2·3 inches thick.

The flywheel, of 40 feet diameter and 60 tons weight, is built up of ten segments upon a central boss 10 feet in diameter, each of the ten arms being cast separately. The shaft is 14 feet 9 inches long between the journals, which are 23½ inches in diameter and 35½ inches long. The thickness of the flywheel seat is 27½ inches. The crank-pin diameter is 14½ inches.

The side framing, 92 feet in length, is put together in five sections, the holding-down rods being arranged to cover as much of the foundation as possible, the cylinders being sunk below them to such a depth that their central horizontal plane coincides with the middle height of the frames. The masonry foundation is 16½ feet high. The engine-house is in half timber and brickwork, is 168 feet long, 40 feet broad, and 38 feet high, with a travelling crane upon tall legs running upon rails along the entire length; this has a lifting power of 15 tons. Two hydraulic lifting-presses are placed below the flywheel-shaft, and a two-cylinder engine of 15 HP. is provided for turning the flywheel at starting. The air-pump is driven by an independent engine. The total weight of the engine is about 320 tons. It was completed by the makers in the comparatively short period of seven months from the receipt of the order.

H. B.

The Blowing-Engines of Rhineland-Westphalia, Upper Silesia and Austria-Hungary. By A. von Ihering.

(Berg- und Hüttenmännisches Jahrbuch der k.k. Bergakademien, 1892, p. 381.)

With a view of obtaining accurate information relating to the construction and working of the blowing-engines used at the blast-furnace and Bessemer works in Germany and Austria, the Author has collected from the directors of the various works full details relating to this subject. The information is printed in tabular form, and covers upwards of fifty pages, particulars being given of

227 engines at 84 works. The distribution of the blowing-engines is as follows:—

—	Number of Works.	Number of Engines.
I. Blast-furnace Blowing-Engines.		
1. Rhineland-Westphalia . .	24	94
2. Austria-Hungary	27	59
3. Upper Silesia	9	38
Total	60	191
II. Bessemer Blowing-Engines.		
1. Rhineland-Westphalia . .	10	17
2. Austria-Hungary	12	17
3. Upper Silesia	2	2
Total	24	36

Classified according to the construction of the blowing-engines, the numbers are as follows:—

I. Blast-Furnace Blowing-Engines.

—	Number of Works.	Number of Engines.
A.—*Beam Engines.*		
1. Rhineland-Westphalia . . .	6	13
2. Austria-Hungary	4	6
3. Upper Silesia	4	6
Total	14	25
B.—*Vertical Engines.*		
1. Rhineland-Westphalia . . .	17	40
2. Austria-Hungary	12	19
3. Upper Silesia	9	28
Total	38	87
C.—*Horizontal Engines.*		
1. Rhineland-Westphalia . . .	19	41
2. Austria-Hungary	15	25
3. Upper Silesia	3	4
Total	37	70

The total number coming under these classes is thus 182.

II. Bessemer Blowing-Engines.

—	Number of Works.	Number of Engines.
A.—*Vertical Engines.*		
1. Rhineland-Westphalia . .	3	4
2. Austria-Hungary	..	..
3. Upper Silesia	..	..
Total	3	4
B.—*Horizontal Engines.*		
1. Rhineland-Westphalia . . .	8	13
2. Austria-Hungary	12	17
3. Upper Silesia	2	2
Total	22	32

From these figures the following rough generalizations may be deduced: Of blast furnace blowing-engines, beam-engines are in a decided minority, whilst vertical engines predominate. The number of the former is about 28 per cent. of the latter, and about 35 per cent. of that of the horizontal engines. The ratio of the horizontal to the vertical engines is approximately 8 to 10. The number of vertical and of horizontal engines in Rhineland-Westphalia is the same; but in Austria-Hungary the horizontal engines predominate, whilst in Upper Silesia the vertical ones are preferred. The total number of blast-furnace blowing-engines is 182, whilst in the first Table it was given as 191. The 9 engines wanting are not included, inasmuch as they are driven not by steam but by hydraulic power.

For Bessemer works, horizontal blowing-engines are everywhere preferred to vertical ones, the preference being easily explained by the greater stability requisite for the great number of revolutions. Beam-engines are not used at all, and vertical blowing-engines are used only in Rhineland-Westphalia to the extent of some 10 per cent. of the total number. The number of Bessemer works, and of blowing-engines is practically the same in Rhineland-Westphalia, and in Austria-Hungary.

B. H. B.

On the Variability of the Water-Level in Locomotive-Engine Boilers. By Professor Georg Meyer.

(Glaser's Annalen für Gewerbe und Bauwesen, February 1st, 1893, p. 45.)

Attention is called to the changes in the water-level in the boilers of locomotives, due more especially to starting and stopping. By means of diagrams, the Author explains how the water-surface takes an inclined line, being either heaped up over the fire-box in starting or rising rapidly towards the funnel-end in coming quickly to a standstill under the application of brake-power. The angle of inclination can, if the weights of the engine, tender, and train are known, be calculated, and formulæ for this purpose are here indicated, showing the effect of stopping an express train with an assumed total weight of 220 tons, travelling at 56 miles per hour. By the application of these formulæ it is shown that, under the given conditions as to brake-power and friction, the inclination of the surface of the water would be about one in fourteen, or, supposing the total length of the boiler and fire-box to be 18 feet, the fall in the water-level from front to back would be about 15½ inches. It is assumed in this calculation that the water-surface would be bounded by parallel lines, but this is not the case, and as the enclosing lines are curved the slope would not be a uniform one. Various factors, such as brake-resistance, reversal of engine, &c., may tend to increase the angle of inclination, and, as the Author points out, may dangerously expose the top of the fire-box to super-heating. The minimum height of water above the top of the fire-box is, according to the regulations for the chief railways of Germany, fixed at 4 inches, but in coming to a rapid stop, which it is calculated could be effected in the assumed train in a distance of 1,476 feet, the top of the fire-box might be absolutely bare for an interval of 35 seconds. No information is available as to the possibility of heating the fire-box cover to redness in this time with no steam-blast at work, though it is scarcely probable that this could take place. The Author thinks that practical experiments respecting the questions raised are however desirable.

G. R. R.

A New Machine for Cutting and Grinding Thin Sections of Rocks and Minerals. By George H. Williams.

(American Journal of Science, 1893, p. 102.)

This machine was devised in 1891 for the Photographical Laboratory of the Johns Hopkins University, and since then it has been in more or less constant use. It has thoroughly estab-

lished its reputation for accurate and rapid work, while experience has suggested some improvements on the original model.

It consists of a substantial table carrying in its lower part three accumulators and an electric motor, while upon its upper surface is placed the apparatus for grinding and sawing. The table is approximately $3\frac{1}{2}$ feet square on plan, and $2\frac{3}{4}$ feet high. It is constructed, with all its appurtenances, by the Donaldson-Macrae Electric Company. The price of the machine complete is $130 (say £26). It consists of the following parts:—

1. Three 200 ampere-hour storage batteries, 13 inches high, in portable rubber cases. These batteries stand on a firmly constructed cross-piece from which they may be readily removed for recharging.

2. One $\frac{1}{8}$ HP. electric motor of the Donaldson-Macrae pattern. This is fastened to a second cross-piece above the batteries and below the table surface. It is provided with two pulleys from which belts pass to the shafts on the table, which carry the grinding-disks and diamond saw, a circular tin disk 8 inches in diameter with a 1-inch central aperture the periphery being provided with diamond dust secured by cement.

3. The grinding-apparatus: Two circular disks of solid copper, 9 inches in diameter and $\frac{3}{8}$ inch thick, which may be used alternately as different grades of emery are required. They are attached either by a screw or square socket to a vertical iron spindle which revolves smoothly in a conical bearing. The grinding disk is surrounded, when in use, by a large cylindrical pan of tin, which has an opening in its centre to allow of the passage of the spindle.

4. The sawing-apparatus: A horizontal countershaft placed on a different part of the table from the grinding-disk, and connected with the motor by a separate belt. It carries at one end a vertical wheel of solid emery, and at the other an attachment, level table, and guide for the diamond saw. A small water-can and spout is suspended over the level table to keep the edge of the saw wet when it is in use.

Under some circumstances it may be found advantageous to obtain electricity for this motor by a direct wire from an electric light or power company. Considerable inquiry has shown, however, that in Baltimore the storage batteries are more convenient, safe, and economical. A single charging meets the needs of a laboratory of ten students for one month. The batteries are removed by the electric company and returned with little or no delay, at a cost of $3·75 (15*s.* 6*d.*) for recharging.

F. G. D.

On Wittgenstein's Continuous-Sheet Rolling-Mill.

By A. Frappen.

(Stahl und Eisen, 1892, p. 999.)

At the Rudolfshütte, near Teplitz, in Bohemia, a method of producing thin sheet-steel from the ingot, without intermediate cutting into lengths or cooling, has been introduced by Mr. Carl Wittgenstein, the managing director. The plant, designed by the Author, includes a three-high universal and a Lauth mill for cogging and roughing, and five two-high finishing mills, worked in continuous series. The ingot, of 11 to 12 cwt., measuring about 16 inches broad, 12 inches thick, and 24 inches long, is reduced to a slab 2 inches thick and 39 inches broad in the cogging-mill, the edges being kept square by the combination of vertical and horizontal rolls, which make it possible to get a powerful pressure on all four sides. The rough end is then sheared off, and the slab is immediately returned to the furnace to be brought to the finishing heat. When drawn, it is rapidly turned over by machinery to allow the scale and cinder to be removed, and goes to the Lauth three-roll mill, which reduces the thickness to $\frac{1}{5}$ inch (5 millimetres), and delivers it to the live rollers of the finishing mills. These are all placed in the same horizontal plane, at $2\frac{1}{2}$ metres distance apart, so that the roughed slab, without changing direction, emerges in a few minutes as a finished sheet from $1\frac{1}{2}$ to 2 millimetres ($\frac{1}{16}$ to $\frac{1}{25}$ inch) thick. A live-roller train, 50 metres long, is placed on the delivery side, with a shearing-machine at about $\frac{3}{4}$ of its length. Here the sheet is divided by two cuts into three pieces, from 14 to 17 metres long, which can then be carried to the machines for shearing to finished sizes as required.

In order to obtain such very rapid reduction a triple engine-power is necessary. The cogging and roughing mills, which are never both in use at the same time, are driven by an engine having cylinders of 35 inches diameter and 52 inches stroke, and the finishing train by another of 39·2 inches diameter and 54·8 inches stroke. Steam is used at an initial pressure of 120 lbs. per square inch, with a high degree of expansion but without condensation, owing to a difficulty in obtaining injection water. The rolls in all the mills are of the same diameter, 630 millimetres (24·7 inches), and are made of cast-steel; the rolled screws are adjusted mechanically, and the feed-tables, together with the ingot charge and drawing-cranes, are manipulated by hydraulic machinery under pressure from an accumulator. The finishing mills are driven by a train of spur-gearing, which includes fourteen V-toothed spur wheels and pinions of different sizes, in addition to two others driving the live rollers on the intake side.

The total length of the mill from the ingot shears to the end of the delivery roller is about 330 feet, and from the roughing rolls

to the sheet-shearing machine about 200 feet. The finishing mill is in charge of a single attendant, who looks after the adjustment of the rolls, the work being accompanied in its passage by the men belonging to the roughing train. The mill was started in July, 1892, and in November of the same year the output of 30 tons of sheets in 24 hours had been reached. It was originally intended to subject the work to a finishing process, but this has not been found necessary, a sufficiently good result being obtained in the single operation.

H. B.

On Combustion in the Hearth of the Blast-Furnace.

By W. van Floten.

(Stahl und Eisen, 1893, p. 26.)

The experiments recorded in this Paper were undertaken with a view of determining whether it was possible, as had been supposed by some smelters, that with a large volume of blast free oxygen might pass unchanged into the higher regions of the furnace, and so become a source of waste by the premature combustion of the fuel. For this purpose, samples of gas were collected from numerous points between the centre and the circumference of the hearth of a blast-furnace, at the level of twyer centres, and in planes 25 inches above, and 7 to 8 inches below them, and the proportion of oxygen, carbonic acid, carbonic and hydrogen in each was determined by an analysis in Thorner's gas-apparatus. The collecting apparatus, which was somewhat similar to that used by Deville in his experiments on dissociation, was a copper tube of 4 millimetres bore, with a double water-jacket formed by two concentric gas-pipes of $\frac{3}{4}$ and $1\frac{3}{4}$ inch diameter, the cooling-water flowing in through the smaller tube and out through the larger one, the collecting end of the copper tube being turned at right-angles to and brought flush with the surface of the outer jacket. The length of the tube is 2200 millimetres; the outer end is provided with a strong flanged cover, so that it can be driven in to any point up to the centre of the hearth, either through the centre of a twyer, or the embrasure of the bronze water-casing surrounding it.

The furnace, 65 feet high, $19\frac{1}{2}$ feet wide in the boshes, and $9\frac{3}{4}$ feet in the hearth, is blown by five twyers of 4·8 inches, with blast at 5 lbs. pressure, heated to 650° or 750° Centigrade when making white basic iron from a mixture of 2 parts of ore and 1 part of mill cinder, yielding 42 per cent., with 12·4 cwts. of flux, at the rate of 130 tons daily, and consuming coke, with 9 to 10 per cent. of ash, at the rate of 19·4 to 19·6 cwts. per ton of metal.

When a greyer pig with 2 per cent. of silicon is made, the twyers

are reduced to 4·4 inches, and the make to a little over 100 tons, while the coke is increased to about 20 cwts. Occasionally a white steel iron or semi-spiegel with 5 per cent. of manganese is produced.

In all forty-six analyses have been made of gas taken with the apparatus during a period of seven months, under varying conditions of working, and the results are given in a tabular form, which cannot, however, be usefully reproduced without the figures showing the locality of the sample. The following Table contains some of the extremes of composition:—

No.	O.	CO_2.	CO.	H.	N.	O : N.	Locality.
						Per mille.	
2	13·0	6·0	0·0	0·75	80·5	236	Middle of twyer-eye.
11	0·0	0·0	37·0	3·00	60·0	308	Centre point of hearth.
16	0·0	13·5	6·0	0·25	80·25	205	Near edge of twyer-eye.
31	0·0	0·0	33·75	1·75	64·5	262	Midway between 2 twyers.
33	0·0	0·0	45·25	2·00	52·75	421	Close to wall of hearth.
42	0·0	11·0	11·75	2·00	75·25	224	25 inches above No. 2.

The results of the analyses show that intense combustion takes place at the point of admission of the air; but that it is restricted to a very small space, as although the blast is supplied at a speed of about 800 feet per second, the extreme limits at which free oxygen is found are contained within an approximately spherical space, which does not extend more than 24 inches from the twyer centre line, or 25 inches above it. It is clear, therefore, that waste of coke by combustion in the upper part of the furnace by excess of blast passing the twyers unchanged is not possible under the ordinary condition of hot-blast coke or charcoal smelting, whatever the case may be with cold-blast.

It also appears that the first use of the blast is in the maximum oxidation of carbon to, or to carbon dioxide, the oxygen being entirely consumed before there is any production of carbonic oxide. This is shown by the circumstance that oxygen or carbonic oxide are only found together in the gas under exceptional conditions, which may be accounted for by irregularity in the pressure of the air due to the pulsating action of the blowing engine.

Hydrogen appears to be universally present in the gas in the proportion of 0·5 to 4 or 5 volumes, even when there is a notable excess of free oxygen. This, probably, results from the decomposition of water vapour in the blast, and, together with that derived from the moisture in the coke, it passes through the charge, remaining unchanged, like nitrogen, as it is ultimately found in full in the waste gases of the furnace top.

The proportion of oxygen to nitrogen in the gases which, under

normal conditions should be 265 to 1000, is in most of the samples taken from the hearth, considerably lower, being in one instance as low as 205, showing that some of the air is consumed for other purposes than the oxidation of coke, that is in the fining of cast-iron by the oxidation of carbon, silicon, manganese, iron, and phosphorus. There must, therefore, be both oxidizing and reducing regions in the hearth at the same level, oxygen and carbonic acid prevailing in the former, and carbonic oxide in the latter. The extent of such oxidizing areas will depend upon intensity of combustion and volume of blast supplied, diminution of the latter, and increase of its temperature, tending to diminish their size.

To show that oxidation does take place to some extent in the cast-iron passing the twyers, the Author points out that the bears of blast-furnaces are not imperfectly carburized masses of iron, but that they have been actually decarburized and come down melted as they send out branches, filling the openings between the hearth bottom bricks, showing that the metal has been perfectly liquid. A plate of such metal 4 millimetres thick was found to contain—carbon, 0·04; silicon, 0·10; manganese, 0·41; phosphorus, 0·33 per cwt. Such a material, when melted at a high temperature, takes up carbon very rapidly, and, therefore, would be very destructive upon a carbon-lined hearth-bottom; but with grey cast-iron, high in silicon, the oxidizing action is mainly confined to that element, and the effect upon such a lining would be less, as the product would contain more carbon.

From the results obtained in those experiments, the Author has modified the opinions that he formerly expressed upon the subject of scaffolding in blast-furnaces, as it is clear that the descent of the charge cannot be assumed to take place uniformly over the whole section of the furnace. As the burden when it approaches the twyers is already melted, and takes up but little space, the hearth is almost entirely filled with coke, which can only be consumed by oxidation, as it is perfectly unaffected by heat alone, and will, therefore, be unchanged, except in the spaces before the twyers, where carbonic acid and oxygen are found, and these form but a small portion of the whole area of the furnace. The descent of the charge must therefore be effected in as many separate small funnels as there are twyers, the motion being most rapid at the bottom, and the scaffold instead of extending over the whole furnace, forms separately for each twyer. The area of the bottom of the funnel is contracted by any increase in the intensity of combustion, and diminishes in the supply of blast, whether accidentally or by design. Very hot blast, as coke at a high temperature or in small pieces, weak and easily crushed fuel, small ore, and excessive separation of carbon, are all causes having a similar tendency.

An arch when formed mainly of coke and carbon cannot be loosened by heat, but only by oxidation; but during the hanging of the charge, the blast diminishes in quality because the hollows become gradually filled with carbon, and as the oxidizing carbonic

acid cannot penetrate, the impediment can only be made to fall by removing the support below. This may be done by means of cold or very dense blast, or by blowing the hearth empty. The bearing arch sometimes formed across the entire furnace when the latter method has been adopted is not, however, the cause, but rather the consequence of the hanging of the charge as resulting from the formation of similar partial obstructions over the separate twyers. As an example, on October 24th, 1892, when the furnace was driving slowly but perfectly regularly, the gas taken from a point where, under ordinary circumstances, both oxygen and carbonic oxide prevailed, suddenly showed 32½ per cent. of carbonic oxide, and no carbonic acid; within half an hour the charge set in the furnace, and remained hanging for several hours, the area of the hollow of the funnel having become so small that the fall of the materials was stopped.

From a consideration of these facts, it is easy to see that very wide furnaces have a greater tendency to scaffold than narrow ones, and also that when it is necessary to diminish the working power of the furnace it is better to stop up one or more twyers, continuing to blow with the full size of the reduced number rather than to reduce the pressure of blast uniformly over the full number. In the first case, there will be fewer funnels formed in the furnace, but they will be of their normal size, and therefore less liable to disturb the working of the furnace by angular fall of the materials than the larger number of smaller ones.

H. B.

On an Improved Open-hearth Furnace. By H. Dowerg.

(Stahl und Eisen, 1892, p. 989.)

At the Friedenshütte, in Upper Silesia, a modification of the Siemens furnace has been introduced by the inventor, Mr. H. Schönwalder. The object proposed to be attained is the more exact regulation of the gas- and air-currents, and the exit of the spent flame, so that when the brickwork begins to waste irregularly, in consequence of the heat being too great at any particular point, the flame may be changed in direction and made to bear upon another part of head wall of the interior. For this purpose the number of regenerators is increased, so that each gas- or air-passage may have its own, instead of two or more of them discharging into the same regenerator as is usually done. A vertical sliding damper of firebrick is placed in the channel between the reversing valves and the regenerators, so that the flow of gas through any one of the passages, whether into or out of the furnace, may be varied independently. The principal modification in the construction is the addition of a middle wall running the whole length of the substructure, which divides the ordinary two pairs of regenerators

into four, those in front, or on the tapping side of the furnace, being connected with the reversing passages by a single large flue, while the hinder ones have each two smaller flues, so that there is a line of twelve dampers on the same vertical plane. The first furnace built on this principle was so successful that the number of 12 to 13 ton-heats, which formerly averaged about 150, was raised to 302, giving a total of 3,740 tons of ingots of basic mild steel, without losing more than $\frac{1}{4}$-brick thickness in the roof. The wear of the gas-ports, though more regular than formerly, was still considerable, and therefore in a further modification the gas- and air-passages were carried up in separate stacks, like those of the Bathio furnace, with their inlets placed obliquely to the axis of the furnace. The No. 2 furnace, with these improvements, was in perfect condition after 325 heats, and the No. 1, which had already made 302 heats, when rearranged with the improved ports, was re-lighted on November 14, 1891, and remained at work until July 11, 1892, without stopping for repairs. During this period of two hundred and five working days 712 charges were worked, producing 8,562 tons of ingots, or an average of 347 heats of 12·025 tons, or 40·852 tons per day. Of these

532 heats	contained	less than	0·05	per cent.	phosphorus.
162 ,,	,,	between	0·05 and 0·08	,,	,,
18 ,,	,,	above	0·08	,,	,,

while the carbon was—

Below	0·1	per cent. in 592 heats.
Between	0·1 and 1·2	,, 103 ,,
,,	0·2 and 0·5	,, 15 ,,

The cost of the alterations is about £200 per furnace, including chains, pulleys and other arrangements for handling the dampers. The principal structural alteration is the diminution of the capacity of the regenerators by the thickness of the middle wall, which, however, gives a third point of support for the cross-girders carrying the hearth of the furnace. The saving in cost due to the increase of the life of the furnace from 150 to 700 heats is estimated at about 2*s.* 2*d.* per ton of ingots, and the increase of production at about 27 per cent.

H. B.

The Influence of Cold on the Strength of Iron and Steel.

By Captain E. Kuczera and Captain Eug. Reinisch.

(Mittheilungen über Gegenstände des Artillerie- und Genie-Wesens, 1892, p. 679, 1 Plate.)

The Authors give an account of tests made on the wrought-iron and steel used in the construction of gun-carriages (in Austria), with the object of ascertaining the influence of temperature on

the strength of the materials. Up to 1890 no breakages of gun-carriages had occurred which could be ascribed to the effects of cold, but in the winter of 1890 no less than four took place, although the temperatures at the time were not lower than 13°·64, 28°·76, 19°·04, and 26°·06 Fahrenheit respectively.

In order to determine in how far these accidents were due to low temperature, a series of experiments was undertaken with the sanction of the War Office. In these experiments similar pieces of the same material were tested at ordinary temperatures, and also at the temperatures likely to occur in winter, while old as well as new material was employed, with the object of finding out whether it had deteriorated by use from repeated vibrations. It was thought that such deterioration might possibly be the cause of failure rather than the cold.

The pieces were subjected to two kinds of impact-test, longitudinal and transverse. For the longitudinal tests the test-pieces were of the form usual for tensile tests, of circular section, 25 square millimetres area, with a tapering octagonal head at each end. The lower head received the blows from a monkey weighing 8 kilograms (17·64 lbs.), falling from a height of 0·5 metre (19·69 inches).

The bars employed for the transverse tests were of rectangular section, 15 millimetres (0·59 inch) deep and 5 millimetres (0·2 inch) broad, and were placed on supports 100 millimetres (3·94 inches) apart from centre to centre. The monkey used had a weight of 4 kilograms (8·82 lbs.), and was allowed to fall from a height of 0·15 metre (5·9 inches). On the underside each test-piece was nicked across the middle with a file, as it had been found by experience that pieces so treated afforded a very good criterion of the tenacity of the material.

The samples tested consisted of: (1) Bessemer steel for gun-carriages; (2) Bessemer steel for gun-carriage axles (hardened and unhardened); (3) wrought-iron, as used for ordinary "angle-bar"; (4) steel from an old gun-carriage axle; (5) steel from the fractured carriage of a mortar.

The test-pieces were cooled in a solution of ice and salt at a temperature of −4° Fahrenheit; they were plunged in this mixture after each blow. The uncooled test-pieces were tested at a mean temperature of 68° Fahrenheit.

In every case the average results were taken of a series of five tests, while for purposes of comparison duplicate samples of each quality of material were subjected to the ordinary tensile tests. The results are given in detail in the original; they may be summarized as follows:—

(1) The resistance of both steel and wrought-iron to transverse impact was less at low than at normal temperatures, a smaller number of blows being required to produce rupture under the former condition.

(2) Wrought-iron was less affected by cold than steel, but the latter is, on the whole, the better material.

(3) Hardened steel was very unsuitable for resistance to impact in both the warm and cold state.

(4) The resistance to longitudinal impact of all the materials tested was increased to a remarkable extent by the reduction in temperature, while the elongation also became greater.

(5) The strength of the axle-steel was impaired by use.

The results obtained with steel from a cracked gun-carriage afford reason for doubting whether the elongation, as measured in ordinary tensile tests, is a reliable criterion for the toughness of the metal, since although the resistance to impact (both transverse and longitudinal) was low, yet the elongation with the ordinary tensile test came up to the prescribed official standard. The Authors also point out that the elongation (during the longitudinal impact tests) was greater at the lower temperatures, in spite of the fact that the toughness, as indicated by the resistance to transverse impact, was less.

The following Table contains the mean results:—

Material.	Longitudinal Impact.		Transverse Impact.		Tensile Tests.		Condition.
	Mean Number of Blows causing Rupture.	Elongation Per Cent.	Mean Number of Blows causing Rupture.	Deflection at Middle. Inches.	Breaking Stress, Tons per Square Inch.	Elongation Per Cent.	
New gun-carriage steel	13·0	30·0	26·6	0·6	30·7	24·8	Warm.
	20·6	36·4	9·4	0·17	30·09	26·7	Cold.
New steel from gun-carriage axle, unhardened	13·6	14·8	11·4	0·307	..	..	Warm.
	30·3	24·1	5·2	0·165	..	..	Cold.
New steel from gun-carriage axle, hardened	1·0	..	1·0	..	..	..	Warm.
	1·0	..	1·0	..	..	..	Cold.
Wrought-iron from angle-bar	5·6	18·4	23·6	1·83	..	..	Warm.
	8·2	20·8	16·7	0·86	..	..	Cold.
Steel from old gun-carriage axle	9·2	24·0	11·8	0·335	..	..	Warm.
	15·0	29·1	1·8	0·051	..	..	Cold.
Steel from broken mortar-carriage	8·4	25·1	1·0	..	29·62	22·05	Warm.
	14·6	26·8	1·0	..	..	..	Cold.

G. R. B.

On the Hardening of Steel.

By W. Metcalf and J. W. Langley.

(Transactions of the American Society of Civil Engineers, vol. xxvii. 1892, p. 382.)

As the result of numerous experiments made at the Crescent Steel Works, Pittsburgh, Mr. Metcalf considers that the hardening of steel may be sufficiently well accounted for by Professor Langley's hypothesis of enforced solution of carbon in iron by sudden cooling, the amount of hardness being a direct function of the rapidity of cooling. There may be a change from cement to hardening carbon, and of iron from an α to a β condition at the point of recalescence, and a definite carbide present as cement in hardened and absent in unhardened steel, but there is no proof of the occurrence of such changes or the existence of such a compound.

One of the most important properties of steel is that, when heated from a cold state to any colour that can be seen by the eye and then cooled down, the grain of the fracture always registers the highest temperature to which it has been subjected, modified of course by the mode of cooling and the treatment while cooling. For similar conditions of heating, cooling, and working, the final result will be always the same. This property is so distinctive in steel cooled from fusion that the carbon contents may be estimated by the fracture to within 0·05 per cent.

As a guide to the engineer in estimating quality from fractures, it may be stated that:—

If a fracture shows a uniform grain throughout, the mass has been uniformly heated and worked.

A coarse lustrous grain of a yellowish cast indicates too high a heat.

A fine lustreless grain, steely blue or grey, shows that a proper heat has been used.

A fine grain, black or of a blackish cast, shows working too cold.

If the grain be decidedly uneven, the piece has been heated or worked unevenly or both. In this case injurious strains in the mass are inevitable, as every change in grain is accompanied by a change of specific gravity and consequently of volume.

If the outside be fine-grained and the centre coarse and fiery it shows high initial heat, modified by superficial and insufficient working either under the hammer or in the rolls.

If the inside be fine-grained and the outside coarse and fiery it shows that the last heat was too high, too quick, and superficial.

If the corners be coarse and fiery, and the body of the piece of a proper grain, it shows carelessness in heating, allowing the corners to run up much hotter than the body.

All of the above indicate the value of annealing in every case where there is reason to suspect unevenness of heating or working;

for if a piece of steel be heated to, or a very little above, the temperature of recalescence (practically a medium orange colour), it will take the fine grain due to that colour, and if the heat be uniform throughout the mass the grain will be uniform, and all strains will be reduced if not eliminated entirely.

As regards colour, the only cherry-red, if there be such a colour, is the heat that just begins to show on heating up or where colour begins to disappear in cooling. This is a critical, dangerous temperature, and no work should be done upon steel at this heat. Above this point the true colours in ascending order are: orange-red, dark orange, medium orange, dark lemon, medium lemon, light lemon, or granular or fusion. There is no true white colour except in liquid steel enormously over-heated.

If a bar of tool steel, with about 1 per cent. of carbon, about $\frac{3}{4}$-inch diameter, is divided by nicking into six sections each about $1\frac{1}{2}$ inch long, and heated at one end so that No. 1 piece shall be nearly white hot and scintillating, while No. 6 is not red hot, the appearances presented by the intermediate parts will be: No. 2, yellowish white; No. 3, lemon yellow; No. 4, orange; and No. 5, reddish orange. When cooled in water and broken, the character of the fractures will be: No. 1, coarse brilliant sand-like particles which crumble very readily; No. 2, similar, but with a finer grain than No. 1, and probably cracked; No. 3, grey crystalline background with sandy particles; No. 4, fine-grained satiny lustre, the individual grains about $\frac{1}{5000}$ inch apart—this is called the refining point; No. 5, coarser grained than No. 4 with a softened lustre; No. 6, more decidedly crystalline and coarser grained than No. 5, the lustre softened as though an infinitesimal film of oil was on the surface.

When tried with a file, No. 1 will be found to be glass hard, but without strength; No. 2, glass hard and a trifle stronger; No. 3, very hard and moderately strong; No. 4, scratches glass with difficulty, but is very strong and elastic; No. 5 can be filed and is very elastic; No. 6, soft. The refining point is a critical temperature at which all steel should be hardened, but it is not fixed, and moves up the scale towards the hotter end as the carbon diminishes.

The maximum rate of change from soft to hard occurs near or at the refining point. If the chilled bar is tested with a file, beginning at the cold end, a very slight increase of hardness will be felt until near the refining point, when the file ceases to bite and slips over the remaining surface of the bar. If, however, a diamond-point is used, it will be apparent that the hardness goes on increasing in the portions chilled from higher temperature towards the end.

That the hardening of steel is accompanied with an increase of volume setting up powerful stresses is proved by the cracking of over-heated pieces and the retraction of the edges of a ring of hardened steel when broken. The amount of this change was determined in 1876 by Professor Langley for several kinds of steel

made at the Crescent Works, the results of which are summarized in the following Table :—

—	Carbon.	Specific Gravity.						
		Ingot.	Rolled Bar.	Sections of Water-Hardened Bar.				
				No. 5.	No. 4.	No. 3.	No. 2.	No. 1.
No. 1. .	0·502	7·855	..	..	..	..	..	..
„ 2. .	0·490	7·836	..	..	..	..	..	..
„ 3. .	0·529	7·841	7·844	7·831	7·826	7·823	7·814	7·818
„ 4. .	0·649	7·829	7·824	7·806	7·849	7·830	7·811	7·791
„ 5. .	0·801	7·838	..	..	..	..	..	..
„ 6. .	0·841	7·824	7·829	7·812	7·808	7·780	7·784	7·789
„ 7. .	0·867	7·819	..	..	..	..	..	..
„ 8. .	0·871	7·818	7·825	7·790	7·773	7·758	7·755	7·752
„ 9. .	0·955	7·813	..	..	..	..	..	..
„ 10. .	1·005	7·807	7·826	7·812	7·789	7·755	7·749	7·744
„ 11. .	1·058	7·803	..	..	..	..	..	..
„ 12. .	1·079	7·805	7·825	7·811	7·798	7·769	7·741	7·690

No. 5 black hot. No. 1 scintillating.

No. 5 shows the state of the metal at an incipient red heat, which is enough to remove the compression due to rolling, and probably all internal strains, and gives what may be called the normal density. No. 4 shows the refined and hardened metal; consequently the stresses due to hardening will be proportional to the differences between the figures in that column and those in No. 5, which are slight; but if the metal has been cooled from the higher temperatures corresponding to Nos. 3, 2, or 1, the differences from 5 are much larger, and hence a greater liability to rupture. Steel very rarely cracks if hardened at the refining point.

As regards the use of tungsten in steel, it is pointed out that the popular belief that tungsten renders iron very hard is erroneous; for if a steel be chosen not excessively high in manganese and carbon, as all self-hardening steels are, no amount of tungsten will make it file hard, if allowed to cool spontaneously in the air. The alloy of iron, with 30 per cent. of tungsten, can be filed. The true function of this element is to delay the rate of change of carbon, whether going in or out of solution, its action being somewhat like that of glue upon the solvent power of water for common salt, the final solubility being not much affected by the glue, but the rate of solution is enormously lengthened. This results in giving to a lathe-tool of tungsten steel the power of taking a heavy roughing cut at a considerable speed, which, of course, heats the tool considerably, but does not draw the temper; whereas a plain carbon-steel tool would, under similar conditions, have some of its carbon thrown out of solution, and become softened. Ordinary steel, when touched on the surface of a rapidly revolving emery-wheel, gives off a shower of brilliant

sparks, which explode into smaller fragments when projected to some distance from the wheel, owing to the combustion of the contained carbon; but tungsten steel gives off only a dull red fire, free from bright exploding sparks. The difference is so marked that less than 0·5 per cent. of tungsten may be readily detected by the emery-wheel test, which is due to Professor Langley.

In studying the phenomena of recalescence, the Authors have carried out some experiments, which throw additional light on the phenomena of hardening. Wires of steel, with 1·3 per cent. of carbon, varying in diameter from 0·035 to 0·250 inch, were heated by electricity and allowed to cool. The smaller sizes would cool down to nearly black before recalescence set in, when the temperature rose suddenly to an orange colour, and then faded slowly away. When a cold wire was slowly heated, there was a prolonged arrest at a dark orange colour, when a sudden apparent access of heat would set in, and the wire go rapidly to higher temperatures. These phenomena make it possible to determine the point of recalescence very sharply by the eye alone, provided it has had some training in the estimation of temperature. The point of recalescence is identical with the refining point, or that temperature which is best for hardening.

If a wire be heated to a lemon colour, allowed to cool to nearly black, and then plunged into water before recalescence takes place, it will be thoroughly hardened; but if heated from the cold state to the same temperature, it will not harden. This apparently contradictory behaviour may be explained as follows: During the heating of the wire just below 655° Centigrade (Roberts-Austen's temperature of recalescence), a breaking up of the crystals and a rearrangement of the particles take place. Heat becomes latent, and is stored up as in the melting of ice. During the cooling of the wire, heat radiates away uniformly till the recalescence point is reached, when the latent heat becomes available at or below 655°, and a brightening of the colour results. A small wire loses heat so rapidly that it can fall considerably below 655° before the particles have been able to take up their permanent or cold position. Hence the potential heat is still in them, and hardening occurs to the same degree as though the sensible temperature was higher because of the time lag. The capability of hardening is thus shown to be a function of molecular arrangement, and not of heat. Hardening seems to be dependent upon temperature, only because the latter is the best means of bringing about the favourable molecular condition.

As a result of these observations and experiments, the following working hypothesis is offered by Mr. Metcalf, with which both Authors are in accord.

The solution of carbon in steel above the point of recalescence is practically perfect, unless the dose of carbon is very large. At and below that point the excess of carbon tends to crystallize out, and therefore very rapid cooling of the steel is necessary to keep it in solution. Also the formation of large crystals is prevented,

and only small ones, corresponding to the refining grain, are produced. This disturbance of the crystalline force results in violent molecular stresses, which produce hardness in a manner analogous to cold-rolling or hammering. The function of the carbon is so to alter the ordinary molecular aggregation of the iron that this strained grouping can be brought about within easily managed temperature limits. Similarly, annealing is a partial throwing out of solution of previously dissolved carbon.

The hardening or chilling of cast-iron follows the same general law, only, owing to the greater amount of carbon and silicon present, the cooling must take place from the temperature of fusion.

The relation of carbon to melted iron is one which lies very near the border line, separating typical chemical combination from typical solution, if indeed any such separation exists. Hence the customary terms framed to denote one or other of these states do not adequately express the shades of difference between the actual phenomena to which they are applied.

H. B.

On the Comparative Longitudinal and Transverse Strength of Mild Steel. By F. Kuitzlé.

(Stahl und Eisen, 1892, p. 686.)

The assumption that mild steel, unlike wrought-iron, is substantially of the same strength, both parallel and perpendicular, to the direction of the elongation developed in the ingot by the rolling mill having been disproved by the experiments of Professor Tetmajer and the Austrian engineers' committee on bridge-building material, a joint commission of the engineering, architectural, and metallurgical societies in Germany was formed for the further investigation of the point, in order to obtain answers to the following questions:—

1. Is it possible, with a material having a longitudinal tensile strength of 23·5—28 tons per square inch, with 20 per cent. elongation, to guarantee similar results with tests cut transversely?

2. How far is it possible to guarantee that test-pieces cut in either direction, when cooled from a red heat in water at 28° Centigrade, will stand bending round a diameter equal to their own thickness without cracks of any kind?

Circulars asking for test-pieces prepared according to a uniform pattern having been addressed to the principal makers of mild steel in Germany, a large number of these, representing bars, plates, and girder rolled in ordinary plate and "universal" mills, varying from 5 to 25 millimetres in thickness, were sent to Professor Krohn, of Sterkrade, and tested by him jointly with the

Author, the total number satisfying the initial conditions being as follows on the three kinds of products:—

—	Universal.	Plates.	Girders.
Tensile tests—			
Longitudinal . . .	234	193	40
Transverse	234	193	40
Total . . 934	468	386	80
Bending tests—			
Longitudinal . . .	190	148	10
Transverse	190	148	10
	380	296	20
Longitudinal averages—			
Tensile strength . .	25·34 tons	25·21 tons	25·71 tons
Elongation strength .	27·5 per cent.	25·5 per cent.	27·4 per cent.
Transverse averages—			
Tensile strength . .	25·97 tons	25·40 tons	25·34 tons
Elongation strength .	22·8 per cent.	24·3 per cent.	24·3 per cent.

An analysis of the individual results shows the number and proportion of failures in the transverse tests to be:

	No. Per Cent.	No. Per Cent.	No. Per Cent.
For 25–28 tons and 20 per cent. elongation .	63 = 27·00	22 = 11·42	1 = 25
For 25–28 tons and 17 per cent. elongation .	43 = 18·37	17 = 8·81	1 = 25
For 23–28·6 tons and 20 per cent. elongation .	24 = 16·00	7 = 3·78	1 = 25
For 23–28·6 tons and 17 per cent. elongation .	19 = 8·12	3 = 1·60	0 = 0

The bending tests were carried out with samples cut in each direction, both in the soft and water-hardened states; but no sensible difference in durability was observed between them. As regards the transverse and hardened specimens with which alone the Commission was concerned, the results upon 358 tests were as shown on p. 451.

About 70 per cent. of the transverse tests showed small surface cracks, while the longitudinal ones were in every case unchanged.

From the results, the Author concludes that it is not possible to guarantee that mild-steel plates and bars shall be uniformly strong and durable in both directions without risking the chance of a large proportion of rejections, which, in the case of bars rolled in universal mills, may be as high as 27 per cent. It seems also to be impossible to avoid superficial cracks in the transverse

bending tests; but these are of comparatively little importance, as they appear in the earlier part of the test when the bend does not exceed 30 or 40 degrees, and in most cases are no larger when the pieces are bent double.

—	Universal.	Plates.	Bars.
Longitudinal	95	74	10
Transverse	95	74	10
Total . . 358	190	148	20

Required diameter of bend—	Number and proportion of failures.		
	No. Per Cent.	No. Per Cent.	
Single thickness, longitudinal . . .	1 = 1·05	0	0
Transverse, double thickness . . .	12 = 12·63	3 = 4·05	0
Transverse, treble thickness . . .	3 = 3·16	1 = 1·35	0

Among the numerous details contained in the Paper, the Author compares his results, as far as it is possible to do so, with those of Professor Tetmajer, whose figures are considerably more favourable. This is probably due to the circumstance that the latter observer worked with tests that were specially annealed; while in the present case the specimens were tested as received.

In conclusion, the Author points out that, although absolute uniformity in strength, irrespective of direction, cannot be obtained in steel, the variation is considerably less than the "good old wrought-iron;" the most unfavourable results with the former showing 15 to 17 per cent. in the transverse tests elongation, as compared with 3 to 4 per cent. in the best quality of iron plates.

H. B.

Some Experiments on the Effects of Punching Steel Plate.

By C. H. Benjamin.

(Journal of the Association of Engineering Societies, Chicago, 1892, p. 463.)

The Author's experiments were undertaken at the Case School of Applied Science, and their object was to determine (1st) the ultimate resistance to shearing for different forms of punches, and the relation of stress to sinking, and (2nd) the effect of punching on the elastic limit and ultimate tensile strength.

A Riehle screw-power testing-machine was used, with ordinary round and square, flat-ended, projecting centre, double step, and

spiral punches. The tests were on Otis steel boiler-plates, 10 inches long, $2\frac{1}{2}$ inches wide, and $\frac{1}{4}$ inch thick, stamped 60,000 lbs. tensile strength.

In carrying out the trials, one plate was reduced in width for several inches near the centre, and broken by tension in the testing-machine, its modulus of elasticity and ultimate strength being carefully noted, as also the contraction of area at fracture. A second piece was cut apart in double shear by a straight die, the ultimate shearing-stress and relation of stress to distortion being observed.

Each of the remaining pieces was punched at the centre of its width and length, readings being taken at intervals of each 2,000 lbs. of load until the punch came through.

A graphic diagram of the relation of sinking to the load applied is given, in respect of which the Author draws especial attention to the entire absence of any yielding- or breaking-down point, the curves, after occasional irregular commencements, due possibly to settlement of the specimen, rising steadily to the maximum.

The results are given in three Tables, the first referring to the load and unit stress, with single tests of all the punches; the second to similar details, averaged from several tests with each of four shapes of punch; and the third dealing with the elastic limit, breaking-stress, contracted area, and elongation of hole of the punched plates.

The first two Tables show that, with the notable exception of the spiral punch, there is little difference in the ultimate unit stress with the other different shaped punches, and that the claim made for the projecting centre-punch of reducing resistance to punching by stretching the metal is not borne out. In the case, however, of the spiral punch, a saving is shown of 23 per cent., the average unit-stress being reduced from 50,000 lbs. to 38,500 lbs.

The tension breaking-tests tabulated in Table 3 vary no more with the different kinds of punch than might be expected from various samples of the same plate. Their average shows 7·5 per cent. less ultimate strength, 5 per cent. increase in elastic limit, and 30 per cent. less contraction of area than in the drilled plate. Where the spiral punch was used, however, the ultimate strength was only 3 per cent. less, and contraction of area only 20 per cent. less than with the drilled plate.

The Author points out that variation in clearance between punch and die may be said to always affect the results, though no very marked differences are shown where the clearance was in one case 0·018 inch, and in another only 0·009 inch; also that good or bad centering of punch and die had much to do with the maximum stress.

Besides the diagram, a full-page illustration of the punches is given.

F. E. B.

On Ferro-Tungsten. By W. H. Wahl.

(Journal of the Franklin Institute, vol. cxxxiv., 1892, p. 470.)

The Author, in connection with Dr. W. H. Greene, has, during the past two years, made a number of experiments with different kinds of ferro-tungsten. These alloys were generally similar in character, possessing considerable toughness and hardness, with a fracture resembling tool-steel, and a range of specific gravity from 9·3 to 10·14.

In some instances the structure did not appear to be homogeneous, the fractures showing smooth cleavage plates of a crystallized material scattered through a finer-grained matrix. A sample of the alloy, of specific gravity 10·14, when boiled several times with aqua regia and fused with alkaline carbonates, gave a heavy black pulverulent residue which was totally unaffected by further treatment with these reagents, and corresponded generally in properties to metallic tungsten; the proportion was 22·54 per cent. of the original alloy. A second sample, when finely powdered and decomposed by fusion twice with mixed alkaline carbonates, gave 22·8 per cent. of a similar residue, which was reduced to 21·74 per cent. by repeated digestion with strong hydrochloric acid of specific gravity 1·20. The complete analyses of the alloy was:—

	Per cent.
Carbon	0·850
Phosphorus	0·041
Silicon	0·140
Manganese	trace
Iron	42·28
Tungsten, free	22·54
„ combined	34·35
	100·201

These figures correspond to a combination of iron and tungsten containing 44·82 per cent. of the latter metal, or almost identical in amount with that required to form the theoretical compound, Fe_4W, which is 45·09 per cent. The Author, therefore, considers that is the definite compound, and that any excess of tungsten in the alloy is present in the free state. He also points out that in Howe's "Metallurgy of Steel" the existence of a compound Fe_3W is indicated as probable from the results of former analyses.

H. B.

A New Copper-Smelting District in Germany.

By B. Kosmann.

(Berg- und Hüttenmännische Zeitung, 1893, p. 29.)

On the southern slope of the Harz an extension of the copper schist of Mansfeld has been discovered, which carries that formation nearly 10 miles further west than its previously known limit. The centre of the new district is at Rottleberode, about 6 miles north-east of Nordhausen, where numerous old workings have been reopened, and a deep level has been begun at 70 metres from the surface, which will prove the deposit for a length of about 2,000 metres. The bed, though generally similar to that of Mansfeld, namely, a bituminous marl containing sulphides of copper and silver, with a conglomerate of copper ores and calcite below, is very much richer and developed upon a larger scale, the total thickness attaining as much as 90 centimetres against 58 centimetres. The proportion of copper in the schist is from 5 to 6 per cent., while the "tresse" or upper part of the sand ore goes up to 10 per cent. The lower conglomeratic portion of the bed, with 1 to 1½ per cent. of copper, is reserved for future treatment by extraction, while the remainder, averaging from 6 to 7 per cent. of copper, is sent to the smelting works. Owing to the smaller depth and larger size of the deposit the cost of working is considerably less than at Mansfeld, or about 18*s.* instead of 35*s.* per ton. The present workings have laid open an area containing about 340,000 tons, which will be increased to 6,000,000 tons by a new deep adit which is intended to follow the course of the bed for the whole discovered length of 15 kilometres.

The roasting of the schist is effected in stalls containing 50 tons, which are connected with a tall chimney to carry the sulphur gases to a distance. The burnt schist, mixed with about an equal weight of the richer ores from the non-bituminous parts of the bed, which contain some quantity of carbonate of lime, and from 1 to 2 per cent. of ferruginous fluor spar, is smelted for coarse metal in a blast furnace 5 metres high. This was originally arranged with a Herbertz steam-jet blower, but it has since been converted into an ordinary water-jacket, 1 metre in diameter, with four tuyeres supplied with blast by a Root blower. The furnace is worked with a closed top, the original steam-jet being used to pass the flue-dust into collecting chambers placed below the level of the ground. The smelting capacity is about 50 tons daily, with a coke consumption of 16 to 20 per cent. The smelted products flow out continuously into one or two of the ore-hearths, where separation of slag and regulus takes place; the former, rising to the surface, overflows into conical slag-pots, in order to allow any entangled regulus to collect at the bottom. When the ore-hearth in use is filled with metal the current is directed to the other one, and the contents are tapped into a shallow cast-iron mould, forming

a thin cake, which is broken up when cold. The coarse metal contains from 40 to 45 per cent. of copper, with about 40 ounces of silver per ton and a little gold. It is sold to the Lower Harz Smelting Works, at prices varying from £17 10*s.* to £18 10*s.* per ton. About 10 tons of charge produce 1 ton of regulus, corresponding to a make of 5 tons per ton from the 50 tons of material smelted. The smelting cost is about 8*s.* per ton of ore.

The reducing-power of the furnace being very energetic, and the sulphur contents low, there is always a certain amount of metallic iron reduced, which separates in the form of iron sows at the bottom of the receiving basin in the ore-hearth. This material, a brittle silver-white steely substance with a largely crystalline structure, is of the following composition:—

Silicon	1·87
Copper	7·34
Iron	70·72
Aluminium	2·71
Nickel	3·20
Cobalt	0·72
Silica, Alumina (slag)	7·00
	6·24
	99·80

Traces of silver, lead, and manganese.
Carbon present, but not determined.

This product has been found to be saleable to iron-works.

H. B.

On the Precipitation of Tin by Zinc. By A. Harpf.

(Oesterreichische Zeitschrift für Berg- und Hüttenwesen, 1892, p. 635.)

A substance known as argentine has been introduced in Germany for making the so-called silver paper which is used instead of tin foil as a packing material. It is a finely divided form of metallic tin, also known as tin dust, of such a texture as to become an extremely fine powder, which must be perfectly uniform in grain, of a bright metallic grey tint, and entirely free from crystalline particles. The Author was for some time in charge of a manufactory of this article, and introduced some modifications in the process, which are described. The raw materials of the manufacture are tin, hydrochloric acid, and zinc. The first may be used in the form of block or grain tin, but generally waste materials, such as bearing metal turnings, which are obtained from railway repairing shops in large quantity, are preferred. These are very variable in composition, including both white and red metal, with the proportion of tin varying from 27·6 to 74·5 per cent. The solution is effected by boiling the alloys with hydrochloric acid in large copper vessels, taking care to keep the

stanniferous material in large excess, under which condition the copper is not attacked, while the greater part of the tin dissolves, lead, copper, and antimony remaining wholly or partially undissolved. The solution is filtered through a layer of sand in a hard-wood tub with a double bottom, where the lead chloride contained in the hot liquor crystallizes out on cooling. The residues are passed on to another establishment to be used in making copper and antimony preparations. The purified solution, consisting essentially of stannous chloride, with traces of antimony, lead, and iron, having an average density of 40° Beaumé, corresponding to about 23·5 per cent. of tin, is diluted from one to two hundred times its volume of water, and transferred to large vats in which plates of zinc are suspended, when, if all conditions are right, the tin precipitates as a uniform grey mass, rendered spongy by the simultaneous evolution of hydrogen, falling, when dried and rubbed through a sieve, to a fine dust. The precipitate is removed every day, fresh liquor is added, and the process is renewed until the zinc chloride solution remaining has reached a strength of 20° to 25° Beaumé, when it is removed and concentrated to 50°, corresponding to a strength of 52 per cent. of chloride of zinc. This is readily sold, as it is extensively used, for preserving railway-sleepers. The finished product should be as nearly as possible pure tin. An average sample analyzed by the Author contained—

Hygroscopic water . . .	0·83 per cent.
Lead	0·60 „
Zinc	0·83 „

the remainder being tin, with small traces of iron, chlorine and antimony.

As the silver paper is used in wrapping up provisions, the tin dust used in its preparation must not, according to the sanitary laws of the German Empire, contain more than 1 per cent. of lead.

In the year 1890 the price realized varied from £7 to £7 10*s.* per cwt.

Formerly silver paper was made by covering ordinary white paper with a priming of white lead and size, upon which either silver leaf or tin foil was cemented. At present this has been almost entirely replaced by argentine, which is made to adhere to the paper by the use of so-called wax solutions, prepared by methods which are kept secret. According to the Author the methods are as follows:—

In the first, 4 kilograms of wax and $\frac{3}{4}$ kilogram of potash are boiled with 50 kilograms of water, and the melting fluid so produced is stiffened to a thick paste by stirring the tin precipitate into it.

In the second, 75 litres of freshly made 4 per cent. starch solution are mixed with 750 grams of a wax solution prepared from 5 lbs. of wax and $1\frac{1}{2}$ lb. of potash dissolved in hot water, and 25 kilograms of argentine are added.

The paste so obtained is printed by rolls on to paper, which dries to a dull grey tone, but becomes bright when burnished by passing through hot calender rollers, when it exactly resembles tin foil. Although the process described above is a very simple one, some difficulty was experienced in obtaining a precipitate of uniform structure, even when at the right degree of dilution, the fine sponge being sometimes mixed with needle-shaped crystals which rendered it unfit for use. This was traced by the Author to the use of waste zinc which was melted down and cast into plates for the precipitating vats, but often contained solder joints and fragments of tin plate. It was observed that whenever a zinc plate containing enclosures of tin or solder was placed in the vat the deposit on the latter was invariably crystalline, while that on the clean zinc was of the proper texture. A further trial with a couple formed by a zinc and tin plate united by an external conducting wire gave a similar result, a spongy mass which was floated up to the surface by the entangled hydrogen being separated by the zinc, while long needle-shaped growths formed on the tin plate extending towards the zinc. Finally, a lead and zinc couple, separated by a diaphragm, was tried, and succeeded perfectly in separating the two deposits. When examined these were not found to differ in any sensible degree in composition, both being tin with small traces of antimony of lead; and the physical difference was also very slight, the spongy deposit being found to be made up of minute but perfectly distinct crystals. The reason for the separation of the same substance at both electrodes is attributed by the Author to a joint electrolytic and chemical action. By the former the electro-positive constituent, tin, is deposited on the lead kathode, while the chlorine goes to the zinc anode and attacks it, but there is a simultaneous chemical action of the latter metal upon the solution in its vicinity, producing chlorine, metallic tin, and hydrogen, which interferes with the growth of the metallic deposit, giving only a micro-crystalline powder. The deposit on the lead, on the other hand, being slowly formed, and from a weaker solution, is denser and more generally resembles that produced in the ordinary electrolytic deposition of metals.

As a result of these experiments the galvanic method of precipitation was introduced by the Author and found to be perfectly well suited, and its use has been continued by the present proprietors of the works.

H. B.

The Gold-Deposit of Pine Hill, California.

By W. Lindgren.

(American Journal of Science, vol. xliv., 1892, p. 92.)

The Author describes a gold deposit which differs in a remarkable manner from the common type of Californian deposits. It occurs at Pine Hill, in Nevada county, and may briefly be described as consisting of veins and seams of barytes, carrying gold and silver, distributed through a kaolinized zone in diabase and diabase-porphyrite. Assays, made on a series of specimens from this deposit, show a large relative amount of silver, more than is usual in the Californian gold-quartz veins. The proportion of gold to silver varies from 1 to 1 down to 1 to 5. The whole altered mass of diabase and porphyrite is auriferous, and barytes is distributed through it in very varying quantities. The quantity of gold contained is approximately proportional to that of the barytes, the latter thus appearing to act as the carrier of the gold. This gold deposit is of interest, inasmuch as barytes is a rare mineral in California, and does not occur in the ordinary gold-quartz veins; and native gold is but seldom associated with this mineral.

B. H. B.

Heating of Armatures. By H. J. Ryan.

(The Electrical World, 1892, p. 260.)

This subject has been experimentally investigated at Cornell University, various drum-armatures of different makes, but all without internal ventilation, having been tested for rise of temperature on a long run. The surface velocity was about 3,000 feet per minute, and the poles covered from 70 per cent. to 80 per cent. of the circumference. The maximum temperature rise was from 70° to 75° Centigrade above that of the surrounding atmosphere, and the amount of heat given off per square inch per degree rise of temperature corresponded to about 0·034 watt. American makers consider a temperature-rise of 75° Centigrade safe. If this limit be adopted, and if T be the temperature rise on open circuit, 75 − T is the temperature-rise due to the armature current C and resistance R; so that

$$C^2 R = 0{\cdot}034 S (75 - T);$$

where S is the surface of the armature in square inches. From this formula the Author obtains the value of the maximum permissible armature current as

$$C = \sqrt{0{\cdot}034 \frac{S}{R} (75 - T)}.$$

For bi-polar armatures the core loss in ergs per cubic centimetre per revolution is represented by the empirical formula

$$H = \left(0{\cdot}004 + \frac{n}{300{,}000}\right) B^{1{\cdot}6},$$

where n is the number of revolutions per minute and B the induction in C.G.S. measure. The Author recommends that before building large machines the rise of temperature to be expected should receive attention.

G. K.

On a New Determination of the Relation v between the Electromagnetic and Electrostatic C.G.S. Units. By H. Abraham.

(Annales de Chimie et de Physique, 1892, p. 433.)

After an introduction in which the Author states the problem and defines the principal terms used, he passes to a historical review of all the attempts which have been made to find the exact relation between the electrostatic and electromagnetic units. The experiments of previous workers, classified according to the methods they employed, are briefly described and criticized, full references to the original Papers being given in each case.

The results are collected in the following Table :—

Author.	Date.	Value of v.
Weber and Kohlrausch	1856	299·60 to 322·60 × 10^8
Maxwell	1868	280·30 „ 290·70 „
W. Thomson and King	1869	271·40 „ 288·00 „
Branly	1872	.. ..
McKichan	1873	286·30 „ 299·90 „
Ayrton and Perry	1879	295·20 „ 297·50 „
Rowland	1879	295·20 „ 301·82 „
Shida	1880	294·00 „ 296·30 „
Stoletow	1881	298·00 „ 300·00 „
Klémencic	1881	299·90 „ 307·00 „
Exner	1882	287·00 ..
J. J. Thomson	1883	296·30 ..
Klémencic	1884	300·10 „ 303·10 „
Klémencic	1886	300·90 „ 301·80 „
Himstedt	1886	299·98 „ 300·98 „
Himstedt	1887	300·31 „ 300·87 „
Himstedt	1888	300·57 „ 301·53 „
Rosa	1889	299·50 „ 300·90 „
J. J. Thomson	1890	299·55 .. ..
Pellat	1891	300·78 .. ..

The second part of the Paper deals with the Author's own

investigations. In order that the possible error might be less than one part in a thousand, it was deemed necessary to avoid methods depending on the use of the absolute electrometer, which does not, according to the Author, admit of greater accuracy than one part in five hundred. For the same reason the ballistic galvanometer was considered unsuitable. The choice lay between the measurement of capacity by the Wheatstone Bridge, and by the differential galvanometer, and for reasons given in the Paper the Author preferred the latter.

The following was the method adopted. A revolving commutator was made to charge a condenser of known capacity, and discharge it through the upper coils of a differential galvanometer a certain number of times per minute. The deflection thus produced was balanced by a continuous current, the intensity of which would be varied at will and accurately determined.

The electromotive force of the battery was about 110 volts. The wires from it led to a Pohl's commutator, and thence to the two sides of a revolving commutator, by means of which they were periodically put in communication with the plates of the condenser. To furnish the continuous current for comparison a very small fraction of the battery current was shunted in the following way:—The wires of the main circuit were connected by a megohm in series with a coil of 500 ohms, and from the two ends of the latter wires were led to the lower coils of the differential galvanometer. Thus a derived circuit was provided, the electromotive force of which was a constant fraction of that of the battery. In order to be able to adjust the current passing through the galvanometer a second shunt was placed across the derived circuit. Between the galvanometer and the 500-ohm coil was inserted a coil of 19,000 ohms, and between the end of this and the junction of the 500-ohm coil with the megohm was placed a box of resistances which could be varied from 0 to 1,000 ohms. The Author shows that the variation of the main circuit caused by the working of this double shunt, and the change of the derived current during the charge and discharge of the condenser, would in each case be less than $\frac{1}{50,000}$ of the whole, and might therefore be neglected.

The condenser was made of glass, optically worked, and silvered on both sides and on the edge. It was provided with a guard-ring, and the distance between the plates was determined with great accuracy by the method of successive reflections.

The revolving commutator by which the condenser was alternately charged from the battery, and discharged through the galvanometer, was fixed to the shaft of a Gramme motor driven by accumulators. A mirror attached to the axis served to compare the speed of revolution with the oscillations of a pendulum carrying a second mirror, the method being an adaptation of that employed by Lippmann for the direct comparison of two pendulums. The current was first increased until the motor ran a little too fast, and an assistant, observing the reflected images through a telescope, applied pressure to the axis so as to keep

them stationary during the experiment. A complete observation occupied about two hours. Several sets of measurements were made with various velocities of the revolving commutator, not exceeding however 40 turns per second, lest the condenser should be insufficiently charged. After each experiment the electrostatic capacity of the commutator, &c., without the condenser was determined. Then, with the dynamo still running at the same speed, the constant of the galvanometer was taken. Experiments were also made with a somewhat different condenser, and with a battery of twice the number of cells.

The following is a summary of the results:—

Date.	Number of Discharges per Second.	Value of v.
April 27	18	$299{\cdot}23 \times 10^8$
,, 27	19	$299{\cdot}20 \times 10^8$
,, 27	25	$299{\cdot}13 \times 10^8$
,, 28	20	$299{\cdot}18 \times 10^8$
,, 28	31	$299{\cdot}04 \times 10^8$
,, 28	37	$299{\cdot}24 \times 10^8$
,, 30	34	$299{\cdot}29 \times 10^8$
,, 30	27	$299{\cdot}44 \times 10^8$
,, 30	18	$299{\cdot}35 \times 10^8$
May 2	31	$299{\cdot}15 \times 10^8$
,, 2	19	$299{\cdot}40 \times 10^8$
,, 2	17	$299{\cdot}41 \times 10^8$
,, 21[1]	27	$299{\cdot}06 \times 10^8$
,, 21[1]	26	$299{\cdot}06 \times 10^8$

Mean value of $v = 299{\cdot}2 \times 10^8$.

The measurements of length, time and resistance were all made with instruments carefully standardised and lent for the purpose, and the Author believes the result above given to be correct within one part in a thousand.

G. J. B.

The Dangers of Underground Conductors of Electricity.

By G. Claude.

(L'Industrie Électrique, 1892, p. 435. 1 Fig.)

This Paper relates specially to the methods of preventing accidents such as have occurred in Paris from the use of underground conductors for the supply of direct currents of electricity. The Author remarks that the time is not very remote when central stations were first established, but that in spite of improvements

[1] Using the other condenser referred to.

in methods of distribution, serious accidents have occurred in the neighbourhood of direct-current mains. These accidents are of various kinds, but the most important present the following features: the gas-pipes in the vicinity of the electric circuits are pitted with numerous holes, of which some go entirely through the pipe. On the other hand, the earthenware conduit receives a deposit of salts of sodium and potassium within its structure, and this deposit may amount to 5 to 8 lbs. weight, although externally the conduit may appear perfectly unchanged. The cables themselves are attacked so strongly that some of even 0·062 square inch section have been eaten through. The action is not merely due to local circumstances, but is general over all the districts supplied with electricity.

The damage usually occurs on branch cables, where the leads are run merely in earthenware pipes, and the lead gas-pipes close at hand are affected. There are, however, cases in which gas-pipes of cast-iron or bitumenized wrought-iron have also been attacked. The Author has found upon a length of 19·6 inches of a cast-iron gas-pipe 7·85 inches in diameter a dozen pits 0·235 inch to 0·315 inch deep, and from 0·039 to 0·118 inch in diameter. The heat of the surrounding soil proved these to have been caused by electricity. The water-pipes have not been affected, as they are placed inside the sewers. Two distinct cables may be connected to the two poles of a distributing centre, and the perforating action will then be produced where the cables come nearest together.

Some have attempted to explain explosions such as that in the Rue Notre-Dame-de-Lorette by supposing an accumulation of hydrogen produced by electrolysis in the conduits, but it was proved that the cause was a gas explosion, and fifty-two branch gas-pipes in the vicinity were found perforated. The Author believes hydrogen is never the cause of the explosions.

The following is his opinion of the causes at work. If the cables are not perfectly well laid, their insulation becomes continually worse, and alkaline matters obtained from the soil are deposited upon the cores of the conductors; a local couple is then formed and the insulation rapidly decreases. The electrolysis continues as the pores of the earthenware conduits become filled with alkaline matter, and acquire more and more conductivity, the cable is eaten away and the leakage has been known to rise to 13 or 15 amperes, causing pitting and punctures in the neighbouring gas-pipes. In order to elucidate the matter, the Author has made analyses and experiments, and finds that the alkaline deposits in the earthenware conduits are of approximately constant composition, consisting of a large proportion of soda, sodium carbonate, potash, potassium carbonate and lead, a smaller quantity of alumina, copper and lime, and traces of iron and silica. The presence of soda, potash, and the carbonates of potassium and sodium is explained by the electrolysis of the alkaline matters in the soil; the copper is obtained from the cable, and the lead from

the gas-pipes. The latter is the most interesting fact, as it proves that the lead is not fused by the currents, but that it is carried over by electrolytic action. In some cases no lead is present, but iron is found, and this occurs when the cable has been laid near iron gas-pipes.

The Author arranged an apparatus to reproduce the action of perforation experimentally. A porous pot was used to represent the earthenware conduit, a conductor of German-silver was curled up in the pot, so as to give as many points of contact as possible, and was connected with the negative pole of a circuit of 120 volts: a lead pipe was then wrapped loosely round the porous pot, and the whole put inside a box, and the space between the porous pot and the box filled up with moist sand and sea-salt. The lead pipe had been unequally covered with a coat of shellac, which was very thin in some places, and it was connected to the positive pole of the circuit. When current was switched on all the features found in actual practice were reproduced, and, after a time, the current rose to 0·75 ampere.

Excrescences of alkaline matter were formed at all the points of contact of the German-silver with the porous pot, and increased continually; the temperature also rose to about 158° Fahrenheit. At all parts of the lead pipe where the coating of shellac was thinnest, the surface was whitened by the action of chlorine, and the parts underneath were pitted with holes, 0·039 to 0·078 inch deep by 0·078 to 0·117 inch diameter. These results prove that the perforations are not caused by local fusion, as the currents are too feeble, and the total volume of the perforations is too great to proceed from the transformation of the lead into its chloride; the proportion of chloride of lead around the tube is very small, but, on the contrary, lead is found among the alkaline matters deposited upon the negative electrode.

From time to time deflagrations occur which may be due to the combustion of sodium, and in a mixture of gas and air these might give rise to accidents such as have occurred in the streets of Paris.

The Author concludes from the results of the tests that the action is as follows: The chlorine produced by electrolysis comes in the nascent state in contact with the lead, and forms chloride of lead, but this being in the electric circuit is electrolysed, and the lead is carried to the negative pole and mixes with the soda and potash, while the chlorine is free to attack the lead pipe more deeply.

This can be easily verified also by the electrolysis of a concentrated solution of common salt, using a plate of lead as the positive pole, and a carbon pencil as the negative; the lead is rapidly attacked, a white precipitate of oxychloride of lead is formed, and a considerable quantity of lead is deposited on the negative pole. In the preceding tests the gas-pipe has been supposed to be in connection with the positive poles, but if it be supposed connected with the negative pole the effects are different. The alkaline

salts will be carried to the lead tube, upon which they will have little effect, while the chlorine passes to the cable, which it eats away, forming chloride of copper. This action has not been observed in practice, doubtless because the passage of the chlorine through the earthenware does not lower its resistance as soda and potash do.

It is evident that the insulation used has not been sufficiently good, and the Author considers that cables should not be run resting on the earthenware of the conduit. The positive cable should be even better insulated than the negative.

He proposes a solution of the difficulty, which consists in joining to the well-insulated positive main a metallic connection attached to the negative and also to the conduit, and putting a resistance of from 50 to 100 ohms in this connection, so as to avoid a short circuit.

The conduit would then only receive a deposit of alkaline matters, even if the insulation of the positive decreased very greatly.

A radical cure would be effected by the use of alternating instead of direct currents, but the Author dismisses this proposal as impracticable at present in Paris.

E. R. D.

The Déjardin Electricity-Meter. By G. Roux.

(L'Industrie Électrique, 1892, p. 489. 2 Figs.)

The Author states that this electricity-meter has been designed by Mr. J. Déjardin with a view to obtain a sensitive apparatus with little waste either at full or no load. It belongs to the class of integrating watt-hour meters. The wattmeter is similar to that of Joule, and consists of a fine wire bobbin hung on the arm of a balance, and placed between two fixed bobbins through which the total current flows. Under the action of the magnetic field created the bobbin is raised, and produces a twisting coupling about the centre of suspension proportional to the energy passing through the apparatus at any instant. The beam is thus slightly raised sufficiently to cause a small wheel, which it carries at its end, to gear with two independent wheels, one of which belongs to the totaliser and the other to the part forming a resisting couple, increasing in magnitude proportionally to the time and actuated by clockwork. So long as the resisting couple is less than the twisting couple the hand of the totaliser moves uniformly, but as soon as the former preponderates, the beam falls and disengages the totaliser.

At equal intervals of time the integration begins again, and lasts a period proportional to the energy consumed during that time.

The integration is caused by clockwork, regulated by a pendulum and running for forty days. The clockwork carries a spindle which makes one revolution every five minutes. The spindle carries a loose pulley upon which is wound a piece of metallic foil; the free end of the foil is attached to the end of the beam, and acts as in the delicate balance of Mr. V. Serrin, which reads to 0·0001 gram. This loose pulley is fixed on the same spindle as a special wheel, and is brought back by a ratchet gear to its original position at intervals of five minutes. The necessary power is supplied by a spiral spring, which slightly overbalances the increasing weight of the foil as it unwinds.

On the beam a spindle carries a wheel, gearing with the special wheel of the loose pulley and also with the first wheel of the totaliser when the beam is horizontal, and leaving the two wheels when the beam falls by the increasing weight of the foil. The beam carries the movable bobbin at one side and a balance-weight at the other.

When no current is passing through the apparatus the clockwork causes the foil to unwind, the increasing weight of the foil causes the beam to tip at once and nothing is registered on the totaliser; but as soon as a current passes through the bobbins of the watt-meter, the movable bobbin is attracted, and the wheel on the beam gears with the wheel on the loose pulley and with the first wheel of the totaliser until the weight of the foil ends the equilibrium. The wheel of the totaliser turns then with uniform velocity for a period proportional to the power at the instant of falling out of gear.

The integration is, however, not continuous, for the foil when unwound must be brought back to its original position; the rewinding takes five seconds, so that integration is continuous for 295 seconds out of 300 seconds.

E. R. D.

Lateral-Illumination Arrangement for Arc-Lamps on Hrabowski's System.

(Glaser's Annalen für Gewerbe und Bauwesen, 15 November, 1892, p. 198.)

By means of a series of reflectors, the arrangement of which is explained by a diagram, and which consists in the main of large vertical and inclined mirrors attached to the wall surface, having opposed to them a smaller series of transparent reflectors, in the centre of which latter is situated the radiant point, the light is broken up and dispersed over a large reflecting area. By this means the intensity of the arc-light is tempered and diffused, half of the illumination being reflected directly from the principal mirrors, and the other half being partially transmitted through the minor reflectors and partially thrown back on to the principal wall-reflectors for re-transmission.

By means of figured plans, the relative brilliancy of the lighting of a room 10 metres by 7 metres in area, used for drawing in a Berlin school, is shown on each square metre of surface at table-height: the new system, being contrasted with a similar diagram, showing the former lighting (by means of two arc-lamps and eight glow-lamps) for each square metre of the same area. The total lighting effect obtained by means of reflectors is set down as 4,599 metre-normal-candles, while for the old arrangement the total effect was 490 metre-normal-candles. From these figures it appears that the value of the arc-lamps was increased more than ninefold by the new reflecting arrangement; the eight glow-lamps were dispensed with, and a white light was produced which had nearly the same brilliancy as that of good daylight. The quality of the daylight illumination, that of the direct arc-lighting and the new lateral illumination by reflectors, is illustrated and contrasted by means of a series of similar photographs of casts of ornament, used as examples for shading.

G. R. R.

The New Station of the Edison Electric Illuminating Company of Boston, U.S. By A. C. Shaw.

(The Electrical Engineer, New York, 1892, p. 119.)

This is a very full description of the new Central Station at Boston, designed for an ultimate capacity of 25,000 HP., and six hundred thousand 16-candle-power lamps connected. The present design is for a capacity of 11,250 HP., and the plant comprises six 1,500-HP. steam dynamos, three 750-HP. steam dynamos, and fifteen 325-HP. boilers, having collectively an evaporating capacity of 146,000 lbs. of water per hour.

The Author prefaces his descriptions of the technical details of the station by a history of the company, which was started in 1886, and began operations with a small station laid out for one thousand six hundred lamps. In the following year a second station was built and equipped with twenty 150-HP. engines and forty dynamos, which plant was, however, destroyed by fire in 1888. The interruption of the service lasted only twenty hours, spare plant being sent on by express train from Schenectady. Another station was started in the same year with twelve engines and twenty-four dynamos; but as this station, and the additions which had been made to the other stations, were found still insufficient to meet the growing demand for light, the company in 1890 determined to lay down the very large station described by the Author, and, with a view to embody in this all the modern improvements, sent their engineer, Mr. Edgar, on a tour of inspection to Europe in 1891. The result of his investigations was to decide for vertical triple-expansion engines, and for a site on the

water front, even at the sacrifice of being at some distance from the electrical centre of distribution. The site selected is on the historic spot where in 1773 the tea was thrown overboard by the Boston citizens. The site contains 100,000 square feet, of which area about one-fifth is now built over. Part of the site is reserved for a coal-store holding 5,000 tons, two derricks being provided for hoisting the coal from the vessels which come alongside.

Minute descriptions are given of the foundations, which are all piled, the sea-wall, and the building. The chimney for the fifteen boilers above mentioned is 11 feet six inches internal diameter, and 200 feet high. The boilers are of the Babcock-Wilcox type, 24 feet long each, with two 42-inch steam-drums. The headers were imported from Glasgow, it having been found impossible to procure them in America strong enough for the pressure of 225 lbs. at which it was decided to work the plant. Only the smaller engines have as yet been erected. They are of the vertical triple-expansion and condensing type, cylinders 16½, 23½, and 38½ inches diameter by 30 inches stroke. Speed, 120 revolutions per minute. They are guaranteed to work with 15 lbs. of steam per IIP. hour. Each engine drives its own condenser, and a dynamo on either end of the crank-shaft capable of giving an output of 1,333 amperes at 160 volts. The dynamos are connected on the three-wire system. They are of the multipolar type, and the field casting is adjustable vertically, so as to allow for wear in the bearings. Weight of each field 14½ tons, weight of armature close on 5 tons.

The Author next gives details of the switchboards and electrical connections within the station, feeders and mains outside the station, and a map of the distributing plant. The article is fully illustrated.

G. K.

Electric Light Installation at the Port of Havre.

By C. Haubtmann.

(L'Électricien, 1892, p. 412.)

The first electric light installation at the outer port of Havre was erected in 1880, and comprised forty-one lamp-posts carrying, at a height of 12 feet 6 inches above the quay wall, Jablochkoff candles of 360 candle-power. The low position of the lamps and their small illuminating power rendered the lighting of the sheet of water in the outer port, and especially its central portion, imperfect, while the cost came to 2½*d.* per hour per lamp. This installation has been replaced last year by one better adapted for the requirements of the port.

The problem was to so light the sheet of water that vessels may enter during the night without the danger of running down small craft, and this required a more general distribution of light, which

has been obtained by placing powerful arc-lamps on steel towers 80 feet high. Each lamp lights a circle of about 100 yards radius. There are fourteen lamps of 20 amperes, arranged in series of seven on two distinct circuits carried on wooden posts overhead. The cost of the whole installation, including boilers, engines, and dynamos, was £3,600, and the annual charge for lighting amounts to £800 ·

G. K.

The Earthing of the Central Wire in the Three-Wire System of Electrical Distribution.

(Elektrotechnische Zeitschrift, 1892, p. 629.)

For some time the Berlin telephone service had been disturbed by currents from the network of the Electric Light Company, and a series of experiments was undertaken to find a cure or mitigation of the evil. In part of the network the central wire had been earthed, but in consequence of a demand from the Post Office insulated central wires were substituted.

The theory in favour of earthing the middle wire over its whole length is, that thereby the current passing through earth in consequence of any fault in either of the outside wires is strictly limited to the locality of the fault, and can therefore have but a small influence on the telephone circuits. This theory was tested by producing artificial faults and short circuits in the network, and taking account of the number of shutters released at the telephone exchanges by each disturbance. The experiments were made with the middle wire insulated throughout and with the middle wire earthed at a large number of points. In all one hundred and forty-seven experiments were made, and these are summarized in two Tables, from which it appears that the disturbances are really reduced by the earthing of the middle wire.

G. K.

Electrical Transmission of Power at the Zauckerode Colliery.

By M. Georgi.

(Jahrbuch für das Berg- und Hüttenwesen im Konigreiche Sachsen, 1892, p. 40.)

The Author gives the results of ten years' experience of electrical transmission of power at the Zauckerode colliery. The electric railway was installed in 1882 at a depth of 720 feet below the surface. It is 2,460 feet in length, 64 feet of it forming a curve with a radius of 60 feet. The current is supplied by a dynamo at the surface. In 1891 the original electric locomotive was

replaced by a Siemens locomotive of improved construction. Experience has shown that of the electrical work developed by the primary dynamo at the surface, the proportion utilized for the transport of a train of trucks and the locomotive was 41 per cent. with the locomotive of 1882, and 56 per cent. with that of 1891, the useful effect of the new locomotive being some 15 per cent. greater than that of the old one. The cost of haulage for a distance of 2,460 feet is calculated to be as follows:—

—	Per Annual Output of 800 Trucks a-day.	Per Truck.
	£ s.	d.
Steam	54 0	0·06
Labour	135 12	0·14
Lubricant	12 0	0·01
Repairs	24 0	0·02
	225 12	0·23
Interest and depreciation of plant	108 0	0·11
	333 12	0·34

The original locomotive having been in use for ten years, it may safely be assumed that the new one will last as long. It suffices, therefore, to allow 15 per cent. for interest and depreciation, whilst 10 per cent. may be allowed for interest and depreciation of the rest of the plant, the machinery at the surface and the conductors. As the cost of the locomotive was £350, and that of the rest of the plant £5,500, the annual sum to be allowed for interest and depreciation is £108. A full truck contains 0·45 ton of coal, so that the cost of haulage per ton-mile is 1·7*d*. If horses were employed instead of the electric locomotive, for 800 trucks in 16 hours, 5 horses, and the same number of ostlers would be necessary. The cost of a horse per shift being taken as 3*s*. 6*d*., and that of an ostler at 3*s*., the daily cost would be 32*s*. 6*d*., or ½*d*. per truck. Thus, the annual saving derived from locomotive haulage in comparison with horse-haulage is £150.

Electric chain haulage was installed at the Zauckerode colliery in January, 1890. It is driven by a Schuckert disk-motor, the current being produced by a Schuckert dynamo, yielding 20 amperes and 410 volts at 880 revolutions per minute. The motor makes 1,150 revolutions per minute. As the velocity of the chain must not exceed 2 feet per second, repeated reduction is necessary. This is effected once by bevel-wheels, and twice by belts. The results of experiments tabulated by the Author show that the electric work imparted to the dynamo, gives an average useful effect of mechanical work of 85 per cent. with mean load, and of 88·8 per cent. with maximum load. Of the mechanical work imparted to the primary dynamo, there was utilized by the

secondary dynamo 65·4 per cent. with mean load, and 68 per cent. with maximum load. The cost of the plant was as follows :—

	£	s.	d.
1. Steam-engine at surface, primary dynamo, and erection of engine-house	359	18	9
2. Electric plant underground, including conductors and telephone	359	0	7
3. Haulage plant, including chain	237	12	6
Total	956	11	10

The cost of working, for a daily output of 500 trucks for a length of 1,050 feet up a height of 28½ feet, was as follows :—

—	Annual Cost.		Cost per Truck.
	£.	s.	d.
Steam	37	10	0·06
Labour	187	10	0·31
Repairs and lubricants	45	0	0·07
Interest and depreciation	107	10	0·17
Total	377	10	0·61

From a comparison of the results of electric haulage by locomotive and by endless chain, the Author concludes that the choice between the two must be determined by local conditions. Haulage by the electric locomotive is better suited for small and medium outputs and distances, and might be advantageously adopted in very many cases where horses are now used. Endless-chain or rope haulage is best suited for the transport of large outputs for a long distance on an inclined plane.

B. H. B.

Electric Transmission of Power. By E. Hartmann.

(Elektrotechnische Zeitschrift, 1892, p. 657.)

This is the reprint of a Paper read by the Author before the German Society of Engineers, and deals with the efficiency and working cost of power electrically transmitted for working machine-tools, lifts, and cranes. When the works of the General Electric Company, of Berlin, were designed, provision was at once made to distribute power throughout the various departments electrically, the system adopted consisting in grouping machine-tools so as to receive power from short lengths of light main-shafting, each length of shaft being worked by an electromotor.

In some special cases each machine is provided with its own motor. In all there are some forty motors in use, with a total of 400 HP., which is distributed by cables from a central station in the works.

Experiments were made to ascertain the total efficiency of power-transmission between the central steam-engine and the various machine-tools, the latter working under ordinary conditions; and it was found that about 64 per cent. of the power developed was actually delivered to the various machines. Full details of these tests are given by the Author.

He also made tests in another works where long lines of heavy main-shafting transmitted about 250 HP., and found that the efficiency under normal conditions of working was only 54 per cent. A further set of experiments concerned the efficiency of helical spur-gear (97 per cent.) and worm-gear (84 to 86 per cent.).

An example is given where the substitution of electric- for mechanical transmission resulted in considerable saving of power. This was a grist-mill requiring 7 HP., and originally driven by shafting which itself required 6·7 HP., giving an efficiency of 51 per cent. After the installation of the electric plant, the efficiency rose to 74 per cent.

The Author next compares electric transmission within a works with the employment of small steam-engines, scattered about in various shops, and receiving steam through long steam-pipes. He finds that under these circumstances not less than 48 lbs. of coal are consumed per HP. hour, whereas with electric-transmission the consumption is reduced to 24 lbs.; and he cites as an example the Railway Works in Görlitz, where 100 HP. is so transmitted.

He next considers the electric-transmission of power for lifts and cranes, and compares it with pneumatic- and hydraulic-transmission, finding that in most cases the electric system is the more efficient. Numerous Tables are given, in which the different losses are shown; and the article concludes with a description and working results of an electric crane at Hamburg.

G. K.

Electrical Installation for the Town of Zurich.

By W. Wyssling.

(Schweizerische Bauzeitung, vol. xxi., 1893, p. 3.)

The alternating system with a pressure of 1,800 volts and large transformers distributing from sub-stations into a network on the three-wire system at 200 volts, has been adopted as being most economical and also as rendering possible the change if required from transformers to motors charging accumulators at the sub-stations.

The generators are located in a previously existing hydraulic-power station at a distance of $1\frac{1}{3}$ mile from the distributing station in the town. Both high-pressure and low-pressure turbines are required, the latter worked directly from the waters of the Limmat, but as the fall is sufficient only in winter for the full power of the station, their driving power is supplemented during spring and autumn by the high-pressure turbines fed from an open reservoir at 155 metres (520 feet) effective height, into which the water is pumped during the idle hours of the day; in summer the power is further supplemented by two steam-engines each of 300 HP. The generators are of the Kapp type, and are connected by suitable couplings and gearing to either the turbines or steam-engines, or both as desired. The high-pressure mains are concentric lead-covered cables with hoop-iron armouring, a lead covering being also introduced under the outer conductor; but the low-pressure distributing mains are composed of three separate lead cables enclosed in earthenware ducts, the iron-sheathing being of course in this case omitted.

From the distributing station the high-pressure mains are continued to sub-transformer stations, eight in number, each containing 4 to 6 separate transformers, bringing the pressure down to 200 volts. These sub-stations are merely iron stands somewhat after the style of the "kiosques" seen in the streets of Paris, the whole outer casing of which can be revolved on a central axis, so that a single door allows access to any part.

The area covered by this net-work is about 1,100 yards square, with a greatest distance of about 1,000 yards from the distributing station.

This net-work supplies both the house-lighting with glow lamps, and the street-lighting with arc lamps; the latter are, however, connected six in series directly to the terminals of the transformer, and are not independently extinguishable.

The charge for current is 7 centimes per 100 watt-hours (6·6*d.* per B. T. U.), with a minimum of 10 francs (8*s.*) per annum for each lamp of any description installed, this condition being introduced for the purpose of limiting the number of idle lamps which might be used only on rare occasions, but which might then cause an unnecessary overloading of the plant.

At the end of last year 36 street arc-lamps were alight, and 3,300 glow-lamps, and 36 arc-lamps installed for private consumers, equivalent in total to 4,500 glow-lamps of 16 candle-power.

F. J.

Factory-Driving by Electricity on the Northern of France Railway.

(L'Industrie Electrique, 1892, p. 415.)

During the last ten years the use of electricity has greatly increased on the Northern Railway of France. The telegraph and telephone circuits have an extent of 5,500 miles, with one thousand five hundred offices. The block-system and its apparatus is used upon 700 miles of railway, and there are five hundred and ninety cabins; two thousand five hundred and fifty-five large electric bells are used for announcing the arrival of trains. There are also in use six thousand two hundred electrical apparatus for working signals and switches at a distance, and one thousand and twenty-seven electric contacts fixed to distant-signal disks. There are eighteen generating stations, with a total of 1,200 HP. This number will be shortly increased to twenty-six, and the horse-power to 2,600; the electric current is now supplied to twenty-five stations, and this number will shortly be increased to thirty-seven. The electricity produced is used for arc and incandescent lighting, and for driving capstans and cranes, for charging accumulators, which are employed while the dynamos are idle, and also for the cells which are used for the trials of electric lighting on the trains.

Until recently the laboratories, store departments, workshops and offices belonging to the electrical department of the railway were scattered in different places, but on the advice of Mr. A. Sartiaux, the chief engineer, all the various branches have now been concentrated at Saint-Ouen-les-Docks, near the steam tramway station on the Quai-de-Seine. Formerly, the whole of the plant was driven by a gas-engine, but Mr. Sartiaux had found that the work of all classes was so intermittent that the power would be supplied more satisfactorily by electricity, using accumulators.

During the building of the station known as Calais-maritime, the Company had constructed a temporary wooden structure upon the quay itself. This building was afterwards removed to Saint-Ouen-les-Docks. The area covered is 2,250 square yards, and the open wharfs are 7,156 square yards in extent, making a total of 9,406 square yards. Railway lines run into these wharves, and also serve the works of the Société pour le travail électrique des métaux and the Société d'éclairage et de force par l'électricité, both on the opposite side of the Rue Lamonta. The trucks are moved about by electric capstans.

All the heavy articles and machines are on the ground-floor, and blocks and tackle capable of lifting 3 tons each are fixed to the roof-trusses. The warehouses and adjoining buildings are lighted by twelve arc-lamps, using 6 to 8 and 12 to 15 amperes run two in series. The offices are lighted by glow-lamps, and

warmed by gas; they are separated from the warehouses and workshops by glass partitions. The physical and chemical laboratories are on the ground-floor, and contain a very complete series of apparatus for the measurement of resistance, insulation, and for photometry. A large current is supplied by the Société d'éclairage et de force. The laboratories are also lighted by glow-lamps and heated by gas. The machine-shops are partly on the ground-floor, and partly on a gallery.

All the machine-tools are driven by electric motors, instead of by a gas-engine of 12 HP. formerly used. The arrangement is due to Mr. Eugene Sartiaux, the head of the electrical department of the Northern Railway Company, in conjunction with Messrs. Hillairet et Huguet, and the existing machines have been altered as little as possible. The Author divides the tools into three groups, the first consisting of large lathes, the second of drilling-machines, and the third of various tools, such as planing-machines, milling-machines, fans and grindstones. There are seven lathes, driven in three different ways. These lathes are each driven by a motor of 1,100-watt power. The motor is placed behind the lathe, and mounted on a cast-iron bed; the armature shaft carries a pinion which gears into a spur-wheel upon a shaft carrying the usual counter-shaft speed-cones. The two parts of the driving-belt, which passes to the cone on the lathe-mandril, run over jockey-pulleys mounted on a slide, and controlled by a lever with a counterweight, which raises the pulleys and stretches the belt. A light pressure upon the lever releases the jockey-pulleys and stops the lathe, while allowing the motor still to run. The motor can be stopped by a switch also, and this is provided with a series of contacts, so that graduated resistances are put in, thus avoiding excessive currents in the armature at starting. Two other lathes are each driven by a two-pole motor of 300 watts. In one case the lathe is actuated by belting, and in the other by friction-gear. Two small watchmaker's-lathes are driven by an eight-pole motor of 65 watts through gut bands. Five drilling-machines are in use: one radial drill is driven by a two-pole motor of 1,100 watts, fixed upon the speed-cone shaft itself, and driving thence to the second speed-cone by belting.

A large drilling-machine, of the vertical type, is driven by a motor of 1,100 watts, and a smaller one by a motor of 300 watts, two very small drills are each driven by a motor of 65 watts. There are also seven other machines of various kinds, and of these the universal milling-machine is driven by a motor of 1,100 watts, the grindstone by one of 1,100 watts, and the ribbon-saw by one of 2,200 watts. The fan in the smiths' shop is the only new tool, and is driven by a motor of 300 watts through a Raffard elastic coupling; this fan runs at 3,000 revolutions per minute almost all day long. A portable drill is used out of doors, and is provided with a motor of 1,100 watts, and flexible cables.

Besides these tools, there are a pulverizer and mixer, used for making the oily ink used on the pads in the office of the Company.

Both of these machines are driven by an old Gramme motor, which was disused.

The whole installation was completed in October, 1891, and has given very satisfactory results. The potential used is 115 to 118 volts, and the Author gives a Table showing the power absorbed by the various machines when running idle and when working.

The milling-machine appears to require most current, taking 11·4 amperes when running light and 15 amperes when at work. Only three types of motors are used, to avoid complication. The average daily consumption of energy has been 11 kilowatt-hours. The current is supplied at the price of 3·65*d.* per kilowatt-hour; the cost is therefore 3*s.* 4*d.* per diem; to this figure must be added the cost of maintenance of the motors, which amounts to 9·6*d.* per day, making a total cost of 4*s.* 1·6*d.* per diem. An Aron meter is used for measuring the current supplied. When a gas-engine was in use, the cost per diem for gas, water, waste, oil, repairs, and maintenance was a little over 10*s.* 5*d.* The attendant who was formerly required to look after the gas-engine and shafting has been dispensed with, and each workman cleans his machine and motor during two hours on Saturday.

E. R. D.

Overhead Lines for Electric Tramways. By Emil Kolben.

(Elektrotechnische Zeitschrift, 1892, p. 605.)

The Author distinguishes between two systems of trolly-wires. In the first, applicable to short lines, the trolly-wire is uninterrupted over the whole length of line; in the second the trolly-wire is divided into sections, each supplied with current by its own feeder. In addition to the trolly-wire (300 to 350 mils diameter) a separate main may be used, connected to it in parallel every 200 yards.

The Author gives numerous diagrams showing the arrangement of feeders, mains and trolly-wire in different cases, and shows by an example how the sectional area in the different parts of the circuit may be calculated. The efficiency of the motors on street cars varies between 87 per cent. for heavy loads and 70 per cent. for light loads; and the average power required per car is taken at 13·1 HP. The voltage at the station is 530 volts, and the mean voltage about 480 volts, whilst the minimum should not be less than 440 volts. The resistance of the return circuit, consisting of rails and the earth, should not be neglected, as it may amount to one quarter of the resistance of the overhead circuit.

G. K.

Tramway-Motors. By E. Kolben.

(Elektrotechnische Zeitschrift, 1892, p. 457.)

In this article the Author discusses the merits of different designs of electric motors for street cars from a practical point of view. One of the points to be considered is a compact design adapted for the limited space under the floor of the car. With wheels of about 30 inches diameter, and the condition that the lowest point of the mechanism must clear the ground by at least 3 inches, this is a difficult problem. All parts must be easily accessible and capable of being exchanged, whilst small weight and large power are essential.

The Author illustrates six different types of motors and gear made by the Edison Company, the Thomson Houston Company, the Short Electric Railway Company, and the Oerlikon Works. The power of these motors, as stated in a Table, varies from 12 to 17 HP., and the weight from 0·75 to 0·90 of a ton. The usual practice at present is to have simple reduction gear 1 to 4 or 1 to 5, and an armature speed of 400 or 500 revolutions per minute, and two motors per car, one to each axle. The loss of power in the gear is from 4 to 6 per cent. The Author does not advocate gearless motors. Reckenzaun's worm gearing is stated to be as efficient as double-reduction gear. The following Table gives the efficiency at full load for different methods of gearing.

Gearing.	Armature Speed.	Efficiency in per cent.	
		Total.	Motor only.
Double-reduction	1,100	60—65	75—85
Worm-and-wheel	1,200	65—68	75—85
Single-reduction	450	80—83	85—88
Gearless	110	82—85	82—85

The motors are series wound and may be coupled in series or in parallel. With the former arrangement, the total electromotive force (usually 500 volts) is divided between the two motors, but in case of one pair of wheels skidding the available power is reduced in both motors. With the parallel arrangement this defect is absent, but to get the power evenly divided between the two motors the current must be split, not through the armatures only, but also through the field, which necessitates the employment of two reversing-switches.

A very important point is the regulation of speed and power, for which two methods are available: (*a*) by resistance in the main

circuit, and (*b*) by subdividing of field coils. The first method is the simpler, but the construction of the rheostats presents considerable difficulties, owing to the limited space within which they must be housed. There is also waste of power, which is avoided under the second method, but the latter necessitates the employment of a very complicated switch and connections. The Author recommends the employment of an iron-clad type of field to avoid magnetic leakage, and give mechanical protection to the armature. There is with external poles the danger that pieces of iron lying on the roadway may be picked up and get into the armature. Whether the field should be bi-polar or multipolar is yet an open question.

G. K.

The Resistance of Return-Circuits, in Electric Street-Railway Practice. By R. L. Warner.

(The Electrical Engineer, New York, 1892, p. 454.)

To test the question of what constitutes efficient and economical bonding of the rails of electrical tramways which serve as return-conductors for the electric current, the Author, in conjunction with Mr. G. L. Thayer, took a large series of observations on several lines in which different systems had been adopted. The measurement of the resistance by an ordinary Wheatstone bridge was found to be attended with certain difficulties, owing to constant or varying local electromotive forces, and the observations were therefore carried out by determining the drop of electromotive force over a certain distance with a given current. The results of five different tracks are detailed, with full descriptions of the bonding used in each, and conditions of weather, &c., the final figures reduced to resistance per mile for a double track being as follows:—

	Ohm.
A. No bonds, dry	0·7675
B. Bonded, and cross-connected, no continuous wire, dry	0·0797
,, ,, ,, ,, wet	0·0717
C. Bonded, continuous wire, wet	0·0207
D. ,, ,, dry	0·0254
E. Bonded, no continuous wire, dry	0·0577

B was bonded with iron wire of different sizes, but principally of No. 3 gauge.

C was bonded with No. 3 copper wire riveted to rails, and soldered at each bond to a continuous copper wire of same gauge, and rails cross-bonded every 200 feet.

D was similar to C, but the bonds were soldered to rails as well as riveted, and the cross-bonds at more frequent intervals.

E was bonded with two No. 4 galvanized iron wires.

The figures show at a glance the necessity for some form of bond,

and further, the advantage of doing it in a solid manner by using copper; the rail-section does not enter appreciably into the resistance, as the calculated resistance of the bonds accounts for almost the whole of that observed.

The Author shows that a great saving in expense and considerable reduction in resistance would follow the abandonment of the continuous wire, and the adoption of a larger section in the bonding wire; and that at the same time a track of practically unlimited carrying power would be afforded.

F. J.

Magnetic Hysteresis. By C. P. Steinmetz.

(Elektrotechnische Zeitschrift, 1892, p. 519.)

This is an extension of the Author's previous research on the law which governs the loss of power by hysteresis and eddy currents, and which he had originally determined for magnetic cycles in which the positive maximum of induction is numerically equal to the negative maximum of induction. The present investigation was undertaken to find whether the law holds good for cycles between limits which are not equidistant from zero. The original investigation showed that the loss of energy in ergs per complete cycle per cubic centimetre may be expressed by the formula—

$$H = \mu B^{1\cdot6} + \epsilon n B^2;$$

where μ is the coefficient of hysteresis and ϵ that of eddy-currents, B being the induction in C. G. S. measure and n the frequency. He found that μ varied, according to the material tested, between 0·002 and 0·082, and ϵ depended, of course, not only on the quality of the material but also on the shape and size of the test-pieces. In the present investigation the test-pieces were in the shape of sheet-iron plates, 1·4 inch wide by 16·5 mils thick, laid together so as to form a rectangular path for the lines of magnetic induction of 16·2 inches mean length. The plates were insulated by paper in the usual way. The core thus formed was wound with exciting coils over the two longer sides of the rectangle, and the power lost was measured by a wattmeter. Tests made with magnetising currents of 170, 110, and 67 frequency, showed that the hysteresis loss per cycle is independent of the frequency. By using an ordinary alternating-current machine, the cycles are symmetrical with maxima of induction, numerically equal but of opposite size. To test the effect of unsymmetrical cycles the Author inserted into the machine-circuit three accumulator cells, so that a continuous current was superimposed upon the alternating current, by which means the limits of induction were made numerically different. Thus, instead of a cycle between + 4,000 and − 4,000, he was able to produce a cycle

between + 6,000 and − 2,000, or + 11,000 and + 3,000, the necessary rheostats and other regulating appliances being provided. The Author describes in detail the arrangement of measuring-apparatus, and gives the results of his experiments in numerous Tables. The magnetic characteristic for sheet-iron is shown in the following Table, where X represents the exciting power in ampere turns per centimetre of path, and B the induction in C. G. S. measure.

X.	B.	X.	B.	X.	B.	X.	B.
1·0	540	5·5	8,550	16	13,320	60	16,060
1·5	1,000	6·0	9,270	18	13,670	70	16,240
2·0	1,700	6·5	9,850	20	13,950	80	16,380
2·5	2,600	7·0	10,280	25	14,520	90	16,490
3·0	3,650	8·0	10,830	30	14,940	100	16,570
3·5	4,740	9·0	11,300	35	15,230	120	16,710
4·0	5,860	10·0	11,710	40	15,470	150	16,850
4·5	6,850	12·0	12,370	45	15,670	200	17,090
5·0	7,770	14·0	12,900	50	15,800	1,000	18,410

A comparison of the power lost with ordinary alternating- and pulsating-currents shows that both the hysteresis and eddy-current losses depend only on the difference between the two limits of induction, but not on the absolute value of the induction, so that the general formula for the loss in ergs per cycle per cubic centimetre is—

$$H = \mu\left(\frac{B_1 - B_2}{2}\right)^{1\cdot6} + \epsilon n\left(\frac{B_1 - B_2}{2}\right)^2,$$

B_1 and B_2 representing the limits of induction.

The Author next describes tests made with Eickemeyer's magnetometer to determine the magnetic characteristic of tinned sheet-iron and grey cast-iron of various brands, and finds that in all cases the above formula is valid. In subsequent numbers of the same journal the Author deals with the magnetic properties of cast- and wrought-steel, mitis-metal, galvanized iron, various alloys of iron, and shows that any magnetic substance may be characterized by three coefficients, namely—

α, the coefficient of magnetic hardness.
σ, the coefficient of magnetic saturation.
μ, the coefficient of magnetic hysteresis.

The Author distinguishes between the "metallic induction" $\mathfrak{B}$ and the total induction B, and defines as the magnetic resistance ρ the ratio of X to $\mathfrak{B}$—

$$\rho = \frac{X}{\mathfrak{B}}.$$

For convenience of calculation he measures the induction in thousands C. G. S. units.

He assumes that this magnetic resistance is the sum of two numbers, one expressing the magnetic hardness, and the other magnetic saturation—

$$\rho = \alpha + \sigma X.$$

Numerous Tables are given to show that this relation is indeed borne out by experiment, and the values of the three coefficients found for various materials are summarised as follows :—

Material.	Coefficient of Magnetic			Saturation B.	For X exceeding
	Hardness α.	Saturation σ.	Hysteresis μ.		
Wrought-iron, sheet iron, mitis metal, and soft annealed cast-steel	0·03	0·055	0·003	18,200	7
Cast iron and low permeability cast steel	2·4	0·095	0·013	10,500	18
Soft wrought-steel and hard cast-steel of high permeability	1·33	0·060	0·020	16,700	40
Steel, glass-hard	8·00	0·100	0·070	10,000	90

The series of articles concludes with a dissertation on the molecular theory of magnetism.

G. K.

Submerged-Chain Tug with Friction-Drum assisted by Magnetic Adherence. By H. Boileau.

(Le Génie Civil, vol. xxii., 1892, p. 58.)

A well-known method of towing barges on rivers and canals on the Continent is that in which a chain is laid down on the bed of the stream and the tug is fitted with a pair of drums, around which the chain passes a sufficient number of times to give the adherence necessary, that, when the drums are turned by steam-power, the chain shall not slip. A great defect of this system, when applied on rivers, is, that the tug is unable to dispense with the chain in going down stream, because in doing so a long length of chain would be left slack at the point where it was cast off, and a displacement of the whole chain would thus take place on each voyage, which would rapidly make it unserviceable. Owing to the tugs on the River Seine fitted with these chain-drums being obliged to descend on the chain, they are only able to compete

advantageously with ordinary tugs in times of heavy flood for up-stream traffic.

To remedy this inconvenience, M. de Bovet has invented an electro-magnetic chain-drum, by which a sufficient adherence for towing purposes is obtained on a single drum, on which the chain makes three-fourths of a turn. The drum is of steel, and cast in two halves. The interior is hollow, and contains an electric bobbin, to which the current is conducted along the middle of the shaft and through a hole left in the casting for that purpose. The faces of the drum are made heavy, and form the poles of the magnet. By experiment with the pulley to be used in practice it was found that 37,000 ampere-turns saturated the magnet, and consumed 4½ HP. to maintain the saturation. With an old worn chain (originally 1 inch diameter) on such a pulley, and three-fourths of a turn, the chain resisted a tension of 6 to 6½ tons without slipping.

A tug has been built at Lyons on this principle for use on the Seine. Its length is 108 feet, beam 16 feet 5 inches, depth 8 feet 10 inches. It is furnished with a screw, by which a speed of 9·3 miles per hour can be attained in still water on 150 HP. with 150 revolutions. The revolutions when towing by the chain are 90 per minute. The chain passes over the deck, being supported by friction-rollers, fore and aft. One half of the deck is kept clear, to enable the chain to be cast off or picked up when necessary. A well is provided where a certain length of slack chain can be stowed. This is necessary, in order to counteract the tendency to displace the chain from its proper position on curves.

In order to assist in demagnetising the chain as it leaves the drum, the small pulley by which the chain is guided away from the drum is also constructed as an electro-magnet. A pulley, similar to the chain-drum, is used as a brake, and, by means of a commutator and rheostat, the brake-power can be varied at will.

C. F. F.

New Sulphuric-Ether Motor. By Max de Nansouty.

(Le Génie Civil, vol. xxii., 1892, p. 73.)

A new type of motor, using sulphuric ether as the working-fluid, has been invented by Mr. P. de Susini, which has given very satisfactory results. The advantages of the vapour of sulphuric ether over steam for engine purposes have long been recognized; and several engines of this kind by Du Tremblay were employed in navigation and otherwise about forty years ago.[1] The defects which prevented his machines from obtaining any great commercial success were chiefly (1) the losses of a valuable liquid by escape; (2) the difficulty of maintaining the working-

[1] Minutes of Proceedings Inst. C.E., vol. xviii. p. 233.

cylinder at such a temperature as to prevent condensation; and (3) the danger of explosion or fire.

The first of these difficulties is overcome in the present machine by the use of a new form of packing, in which glycerine is employed between two rings; the second by steam-jacketing the cylinder; the third by careful construction.

The ether is vaporized in a boiler of the construction of an ordinary surface-condenser, in which steam at a pressure of 35 lbs. per square inch evaporates ether at a pressure of 145 lbs. The ether-vapour passes thence to the working-cylinder, which is of ordinary steam-engine construction, and is jacketed with live steam. The exhaust passes through baffle-plates, which intercept any glycerine carried through the cylinder, and is then condensed in an air-condenser and pumped back into the generator.

Exhaust steam from a steam-engine may be used for generating the pressure, and thus utilize the latent heat of the steam for an auxiliary engine.

C. F. F.

Thermodynamic Study of De Susini's Ether-Motor.

By E. de Marchena.

(Le Génie Civil, vol. xxii., 1892, p. 74.)

An engine of 20 HP., of the type described in the preceding abstract, has been tested, and the results are sufficiently remarkable to deserve a careful examination as to the reasons for the economy it shows compared to steam-engines of similar power.

The working range of temperature is between 120° Centigrade in the generator and 35° in the condenser. The brake-HP. observed was 14·5, and the IHP. 18·1. The consumption of coal was $2\frac{1}{2}$ lbs., and of steam $18\frac{1}{2}$ lbs. per brake-HP. per hour, which is lower than is obtained with steam-engines of that power. The work which a Carnot's ideal engine, between the same limits and supplied with the heat contained in the same amount of steam, would give is 24·5 HP.

The reasons assigned by the Author for the economical working of the engine are:

1. The complete expansion of the vapour is utilized, the lower temperature limit of 35° Centigrade being much below that at which steam would be released.

2. There is no condensation on the walls of the cylinder, or re-evaporation from them. The specific heat of sulphuric ether vapour is positive, while that of steam is negative, *i.e.*, its temperature rises by adiabatic expansion. Even if, then, there were any priming, the expansion in the cylinder would dry the vapour. The vapour is superheated when exhausted. This effect is enhanced by the steam-jacket.

3. There is no abrupt fall of pressure on opening the exhaust; and therefore no evaporation from the cylinder-walls would occur

during the exhaust, even should there be condensed vapour on them.

The conclusion arrived at is, that the use of sulphuric ether enables the economy that is obtained with steam, by the use of two or three cylinders and large engines, to be realized in single-cylinder engines of small power.

C. F. F.

The Physiological Effect of Alternating-Currents.

By W. Krothals.

(Elektrotechnische Zeitschrift, 1892, p. 428.)

In this article an attempt is made to explain the reported safety of Tesla currents by a mathematical investigation. The Author states that currents of ordinary frequency and 1,700 volts pressure are absolutely fatal, but that an electromotive force of 70,000 volts at a frequency of 300,000 may be taken by the human body without danger. He assumes that the human body has not only resistance but also capacity, and using Blakesley's diagram he finds that with a capacity of 0·118 microfarad the current passing through the body would be that due to 100 volts only, although a pressure of 70,000 volts is applied.

G. K.

The Specification of the Prussian State Railways for the Supply of Mineral Lubricating-Oils. By Dr. M. Albrecht.

(Dingler's Polytechnisches Journal, vol. cclxxxv., 1892, p. 67.)

In 1890 the different Prussian State Railways introduced a uniform specification for the supply of mineral lubricating-oils. In this specification, the viscosity of the oils referred to was that of colza oil at temperatures varying from 68° to 122° Fahrenheit (20° to 50° Centigrade). It was soon found in practice that the relative viscosity varied considerably in oils from different districts, and in the specification issued this year the upper and lower limits of viscosity have been extended. At the same time colza oil has been abandoned as standard and distilled water at 68° Fahrenheit (20° Centigrade) substituted. The water is allowed to run through an Engler's viscosimeter at a carefully ascertained temperature, and the viscosity of the oil under examination is ascertained by allowing a portion of it to flow through the viscosimeter at the same temperature. The flashing-point specified is 320° Fahrenheit (160° Centigrade), and the specific gravity at 68° Fahrenheit (20° Centigrade) between 0·900 and 0·925. The oil must be free from water and mineral acid, and be completely soluble in light

petroleum of a specific gravity of 0·67 to 0·70. It must contain no foreign substances, give no precipitate even when stored for a long time, and must not resinify or form a skin when exposed to the air in a thin layer.

The flashing-point is tested by means of an open porcelain crucible heated upon a sand-bath, and the resistance to cold by means of a special apparatus. The Author points out that in testing Engler's viscosimeter, it is of the greatest importance to use not only distilled water but also oil as a check, because the adhesion of oil to the tube is so much greater than that of water that great difference might be found in using apparatus giving uniform results with water only.

The apparatus for testing the resistance to cold consists mainly of two parts; one for producing the standard pressure of a column of water 1·968 inch (50 millimetres) high, and the other for cooling the sample by means of a freezing-mixture. The oil is placed in a U tube and immersed in a freezing-mixture for an hour. It is then subjected to the pressure mentioned, and the oil must then rise 0·3937 inch (10 millimetres) in one of the limbs of the tube before the lapse of one minute. The freezing-mixture consists of one part of bay-salt and two parts of crushed ice, which will reduce the temperature to less than 5° Fahrenheit (− 15° Centigrade). The Author carried out a series of experiments with this apparatus which resulted in the detection of several possible sources of error. It is especially pointed out that any alteration in the diameter of the U tubes or irregularity in the curve will vitiate the results. The india-rubber connecting-tubes must be of a diameter exactly equal to that of the tubes which they unite, and if any solid particles are visible in the oil the friction will be increased and the rise in the test-tube correspondingly retarded. It is necessary to filter the oil before testing in order to obtain uniform results.

As regards the proportion of water, it is stated that $\frac{1}{10}$ per cent. is sufficient to cause a thick mineral oil to sputter and froth when heated, and this test is recommended by the Author. Mineral acids should be entirely absent; but organic acids of a very weak character are generally to be found, and the maximum is fixed at $\frac{1}{10}$ per cent.

The bulk of the railway lubricating-oil used in Germany is from Baku, and the cost at Hamburg about £1 per cwt. Of this amount 61 per cent. is import duty, 31 per cent. cost of transport, leaving only 8 per cent. as the value of the oil itself.

W. F. R.

NOTE.—The subject of lubricating oils has been considered in Professor Goodman's Papers on "Friction," Minutes of Proceedings Inst. C.E., vols. lxxxv. p. 376, and lxxxix. p. 421; also by Mr. C. J. H. Woodbury in a Paper read before the American Society of Mechanical Engineers, vol. i., 1880.

The most recent form of Engler's viscosimeter is described and illustrated by C. Engler in the "Allgemeine Oesterreichische Chemiker- und Techniker-Zeitung," 1892, p. 1547.—W. F. R.

Petroleum in France.

(La Nature, Paris, January 7th, 1893, p. 81.)

The Author asserts that petroleum has been found in rocks of all ages, but chiefly in situations where great cracks have been occasioned in the strata during the upheaval of chains of high mountains, and in the neighbourhood of volcanoes.

Mr. Lebel, whose discoveries at Pechelbronn, in Alsace, have induced a search for it in the adjoining French territory, was guided by the belief that wherever there are fissures containing bitumen, which is petroleum that has lost its more volatile constituents and become oxidized by contact with the air, the oil itself will be found by penetrating below the bitumen. Its presence is likely to occur on ground being reached which contains, in more or less abundance, salt, sulphur, and gypsum, and sometimes also lignite. Usually, however, the oil is found in pockets of limited extent, separated by ground which is sterile, so that it is customary to sink many wells within a short distance one from the other. If it is not found in the first wells that are drilled, such indications of its proximity may yet have been met with that the seeker should not be discouraged, but proceed to drill further.

Wells have been or are being sunk in France at Gabian (Hérault), at the *Fontaine ardente*, near Grenoble, at the Seyssel asphalt mines, near Bellegarde (Department of Ain), and in Auvergne. In the Limagne (Auvergne), the geological strata almost exactly resemble those of Pechelbronn; there is abundance of bitumen, and at Puy-de-la-Poix a well is being sunk by Mr. Arband close to a spring of water, which is both sulphurous and salt, and is mixed with occasional drops of oil, but no deposit of petroleum has yet been reached. At another point in the Limagne a well was sunk in 1892 to a depth of 735 feet, near to the asphalt mines of Pont-du-Château, in which salt-water and viscous bitumen are met with, but as yet no petroleum.

The most promising work is being done by the engineer de Clercy (who has had experience in the petroleum districts in Galitzia), at Pont-Bathu, near Riom, where he has penetrated to a depth of 920 feet. On reaching a depth of 267 feet, and again at 400 feet, the drill passed through beds of bitumen from which sand and gas were thrown up; at 650 feet there was a violent explosion of salt-water, mixed with some oil, and on attaining a depth of 883 feet there was again an explosion of gas which threw up a quantity of fine sand, viscous bitumen, and thick oil, and on being set fire to burnt with a flame 6 or 7 feet in height.

The quantity of oil has not yet been sufficient for profitable works, but hitherto the drills have been sunk by manual labour only, and it is now intended to prosecute further explorations with the aid of a steam-engine. The ground which has been reached is a mixture of sand and clay, beneath which it is anticipated that a deposit of petroleum will be found. O. C. D. R.

The India-Rubber of the Upper Orinoco.

By Dr. Lucien Morisse.

(Annales Télégraphiques, 1892, p. 355.[1])

In 1888 and 1889, the Author undertook a journey to the basin of the Orinoco and Rio Negro, in the course of which a detailed study was made of the methods in use for the extraction of india-rubber. The india-rubber obtained on the Orinoco is identical with that from the Amazon, the latter being known as Para rubber. The trees in both districts are varieties of Hevea, belonging to the Euphorbia family. When the trees are cut down, the roots send up fresh branches, which attain maturity in about five years. It is, however, forbidden by the Venezuelan Government to cut down the trees, and the sap is extracted by tapping them. In Columbia, felling the trees is permitted. The work is chiefly carried on by Indians, and is at present confined to the banks of the rivers, although the whole of the forest region is said to be equally rich in rubber trees. The work is commenced by clearing a path through the forest with short branches leading to the trees. The trees are then scraped to remove moss and other loose substances, and a liana is bent round the trunk at a height of an inch or two above the ground. The liana is placed in a slanting position so that the juice runs towards one side. The ends of the liana are tied together by means of smaller creepers, and the space between the bark and the loop is smeared with clay. At the lower end of the liana a small cup made of leaves, is fixed in such a position that it receives the sap. The trees are tapped every second day, the number of holes made in the bark varying from eight to sixteen. After tapping, the sap continues to run for about three hours. The milk having been collected, a fire is made with resinous wood, in the smoke of which a piece of wood is turned. The milk being poured over this piece of wood at regular intervals, is coagulated, and when the mass of india-rubber thus formed is sufficiently thick, it is removed by making an incision in one side. The Indians adulterate the india-rubber both with inert substances, such as sand, stones, wood, &c., as well as with the milky juice of other trees, chiefly of the Balata family. The tests used to detect admixtures of the latter kind are based upon the diminution of elasticity which results from the presence of balata. The chief action which the smoke has upon the india-rubber is to coagulate it; but the cake is also saturated with antiseptic substances; these prevent subsequent fermentation which would be detrimental to the quality of the product. The method of smoking being very slow, the Author undertook a number of experiments in order to discover a more rapid method

[1] From Nouvelles Archives des Missions scientifiques et littéraires, vol. i., p. 178.

of coagulating the sap. The action of a number of chemical re-agents upon the sap was tested, and several were found to coagulate the india-rubber satisfactorily. The most economical substance for this purpose was found to be ordinary sulphuric acid, one part of which will coagulate about five hundred parts of sap. It was found, however, that india-rubber which had been treated by sulphuric acid alone, soon began to decompose, and was covered with fungoid growth. A small proportion of carbolic acid was therefore added as an antiseptic, and with this addition, the process gave good results. The india-rubber extracted by this method is white and of great purity. It may be coloured dark like the variety known as Para, by adding a small quantity of lampblack to the milk before coagulation. The Author considers this unnecessary, and regards the carbon as an impurity. It is estimated that a European workman could produce by this process about 50 kilograms (1 cwt.) of pure india-rubber daily. The Author gives a number of particulars with reference to the occurrence of the hevea trees in the various river basins, and also describes the system of exploitation which prevails at present.

W. F. R.

On the Relation between the Velocity of Light and the Size of the Molecules in Refracting Mediums. By P. Joubin.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxv., 1892, p. 1061.)

The Author enunciates the following rule for calculating the index of refraction for any substance of which the chemical composition is known.

Let E be the density referred to hydrogen of a molecule M composed of the atomic bodies a, b, c ..., and let p, q, r .... be the number of the atoms of each entering into the molecule M, and finally, let m be the number of times that the actual molecule contains the chemical molecule (or the condensation)

then $$n - 1 = 0{\cdot}97 \times 10^{-4} \times \sqrt{\frac{2\,m\,E}{\Sigma p}},$$

or the index of fraction is proportional to the square root of the quotient of the weight of the molecule by the number of atoms composing it.

For simple substances the law is proved at once by adopting the number of atoms constituting the molecule, and the tabulated results of observation and calculation are shown to be thoroughly concordant, and similarly for more complex molecules.

For liquid and solid substances the numerical value can be deduced from that of their vapours. Thus for water the density compared with hydrogen is about 11,200, or 1,250 times that of

the gaseous molecule, so that this last figure represents the condensation of the liquid molecule, and, applying the formula above, the value of the index of refraction is—

$$0{\cdot}97 \times 10^{-4} \times \sqrt{2{\cdot}\frac{1250 \times 9}{2 + \frac{1}{2}} \times 1250} = 0{\cdot}33,$$

which is exactly the value for water.

The law enunciated may be therefore considered as verified, as far as it is possible to do so, even in its utmost application, from which it appears that refraction depends merely on the mean mass of the molecule.

F. J.

A New Hygrometer. By O. Krell.

(Gesundheits-Ingenieur, 1893, p. 1.)

Owing to the urgent need of a good percentage hygrometer suitable for general use in dwellings, the Author has occupied himself with the subject for some time past. The commonly employed hygroscopes which depend for their action upon the alterations in form caused by the influence of moisture upon certain organic substances (human hair, feathers, straws, &c.), have this advantage over the instruments of Daniel, Regnault and August, that they are capable of furnishing direct readings. They are, however, very liable to derangement in transit and from careless handling, and they fail as a rule to indicate the degree of moisture as a percentage ratio, since they record the same upon some arbitrary scale. The instrument of August, which is based solely upon thermometric readings, is, when once adjusted, incapable of derangement by accidental circumstances of the above character, and it therefore appeared to be, with suitable modifications, the one best adapted for further use. In its general form the apparatus, of which a diagram is given, consists of two juxtaposed thermometers, one of which indicates the air-temperature, while the bulb of the other is surrounded with muslin, kept moist by being dipped into a small vessel suspended below it, filled with water, the water from which rises by capillary action into the twisted muslin. Constant evaporation takes place from the damp muslin, and this action varies in its intensity in accordance with the dryness of the atmosphere. The fall in temperature of the moistened bulb is therefore in direct proportion to the amount of heat dissipated in evaporating the water. The greater the difference between the temperature readings of the two thermometers with the wet and dry bulbs, at any uniform air temperature, the smaller is the amount of moisture in the air, and the same holds good conversely. The Author substitutes for the suspended

vessel of water, a glass tube, open at the top, but capable of being securely closed by means of an india-rubber stopper. The lower end of this tube is drawn out to a small diameter, and is curved into a semicircular form so as to point upwards. This tube is placed on a board between the two thermometers which are graduated to read from 8° to 20° Reaumur (50° to 77° Fahrenheit), between which limits the maximum range of temperature in dwelling-rooms may be assumed to fall. The bulb of one of the thermometers is enclosed in muslin, attached to the upwards-curving end of the water-tube, and above the apparatus is a board with a table giving horizontally the readings for each degree from 8° to 20°, with the temperature indicating each ten per cent. of moisture in the air in a series of vertical columns beneath. By simple reference to this table on reading the temperatures from the two thermometers, the approximate amount of moisture in the atmosphere can be determined at a glance, or if greater accuracy is needed intercalation can readily be made.

G. R. R.

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